July 2017 - June 2018
Annual Report

and

July 2019 - June 2020
Appropriation Request

to the

Tennessee Higher
Education Commission

October 2018

THE UNIVERSITY OF
TENNESSEE
KNOXVILLE

INSTITUTE FOR A SECURE &
SUSTAINABLE ENVIRONMENT

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ISSE MISSION STATEMENT

The University of Tennessee's Institute for a Secure and Sustainable Environment (ISSE) seeks to promote the development of policies, technologies, and educational programs that cut across multiple disciplines, engage the university's research faculty and staff, and grow in response to pressing environmental and security issues facing the state, the nation, and the globe.

Executive Summary

Dr. Terry Hazen, ISSE Director

During 2017-18, ISSE continued to expand its research and outreach, and the pages of this report provide an update of the activities carried out by ISSE staff, students, and ISSE-affiliated faculty. Here is a summary of ISSE activity this year:

- ISSE has supported about a dozen externally funded research projects.
- In addition to its eleven on-going internally funded, faculty-led seed projects, ISSE awarded two new seed projects at the end of FY17. The focus areas for this year's awards were methane and water.
- ISSE-related faculty, staff, and students received several awards during the year (see list of awards below). Along with numerous presentations made to a wide range of audiences, several articles were published, most in peer-reviewed journals (see list of publications below).
- ISSE research projects have engaged more than 50 UT faculty members, one post-doc, 27 graduate students, and 11 undergraduate students.
- ISSE's Tennessee Water Resources Research Center (TNWRRC), under the leadership of Director Thanos Papanicolaou and Assistant Director Timothy Gangaware, continued supporting five on-going water resource projects funded through the USGS 104(b) program and awarded three new projects under this program.
- TNWRRC continued to conduct training programs in erosion prevention and sediment control around the state. Its Level 1 course (fundamentals) was conducted 14 times and attended by 1,260 people. Its Level 2 course (design principles) was conducted five times and 186 persons attended. The Level 1 one-day recertification course was held 16 times and attended by 1,130 people. The hydrologic determination training program had approximately 75 attendees and the refresher course had 66 attendees.
- Assistance by TNWRRC to the Tennessee Smart Yards program (jointly supported by TNWRRC and UT Extension) included management of the program's communications and marketing, including maintenance of their website, native plant database, social media platforms, and production of a quarterly newsletter.

Executive Summary (cont)

- In addition to other projects, the East Tennessee Clean Fuels Coalition, for the third year in a row, managed the annual allotment of State EPA Diesel Emissions Reductions Act (DERA) funding, assisted new fleets across the State, and partnered to develop and designate alternative fuel corridors in Tennessee. ETCF is also assisting TDEC with the VW Environmental Mitigation Trust, which totals almost $46 million, with funds expected to become available in late 2018.
- ISSE's Worker Health and Safety Training Program facilitated training of DOE workers at sites around the country. An online course was expanded in community colleges in areas with DOE facilities.
- ISSE's Methane Center applied for an NSF grant on biocides and the proposal was funded via a group with Juniata College and Michigan Technological College. The Center will submit an NSF Engineering Research Center proposal in the coming year.

ISSE supported a joint China-US FEWSTERN (Food-Energy-Water Systems Transdisciplinary Environmental Research Network) workshop outside of Nashville, Tennessee in December 2017. Approximately 120 US and Chinese researchers from academia, government agencies, and private industry (with expertise in food, energy, water, sociology, and policy) came together in Tennessee to identify challenges, teaming opportunities, proposal development activities, and strategic research planning initiatives.

In the next fiscal year, ISSE will continue to expand its research and outreach. The ISSE Advisory Committee met in December 2017 and offered several suggestions for strengthening ISSE research and outreach.

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Summary of Faculty, Staff, and Student Participation

Faculty & Staff Actively Engaged in ISSE Research

Name	Affiliation
Khalid Alshibli	Civil and Environmental Engineering
Jejal Reddy Bathi	Visiting Professor , Civil & Chemical Engineering, UT Chattanooga
Stephanie Benjamin	Retail, Hospitality, and Tourism Management
Abjijeet Borole	Chemical Engineering
Barry Bruce	Biochemistry and Cellular and Molecular Biology
John Buchanan	Biosystems Engineering and Soil Science
Kimberly Carter	Civil and Environmental Engineering
Jiangang Chen	Public Health
Rachel Chen	Retail, Hospitality and Tourism Management
Virginia Dale	Ecology and Evolutionary Biology
Jennifer DeBruyn	Biosystems Engineering and Soil Science
Kelsey Ellis	Geography
Timothy Ezzell	Political Science
Jennifer Franklin	Forestry, Wildlife and Fisheries
Joshua Fu	Civil and Environmental Engineering
Timothy Gangaware	ISSE, Tennessee Water Resources Research Center
Chris Graves	Forestry, Wildlife and Fisheries
Sue Hamilton	Plant Sciences
Jon Hathaway	Civil and Environmental Engineering
Terry Hazen	Civil and Environmental Engineering; Earth and Planetary Sciences; Microbiology; ISSE
Qiang He	Civil and Environmental Engineering
Don Hodges	UTIA Forestry, Wildlife and Fisheries
Karen Hughes	Ecology and Evolutionary Biology
Mingzhou Jin	Industrial and Systems Engineering
Alfred Kalyanapu	Civil and Environmental Engineering, Tennessee Tech
Anahita Khohandi	Industrial and Systems Engineering
Ungtae Kim	Civil and Environmental Engineering, Cleveland State
Sarah Lebeis	Microbiology
Xueping Li	Industrial and Systems Engineering
Andrea Ludwig	Biosystems Engineering and Soil Sciences
Lisa Reyes Mason	Social Work
Jim Ostrowski	Industrial and Systems Engineering
Jonathan Overly	ISSE, East Tennessee Clean Fuels
Angelica Palomino	Civil and Environmental Engineering
Thanos Papanicolaou	Civil and Environmental Engineering
Mona Papes	Ecology and Evolutionary Biology
Jack Parker	Civil and Environmental Engineering
Hector Pulgar	Electrical Engineering and Computer Science
Claudia Rawn	Materials Science and Engineering
Todd Reynolds	Microbiology
Sean Schaeffer	Biosystems Engineering and Soil Science
John Schwartz	Civil and Environmental Engineering
Jennifer Schweitzer	Ecology and Evolutionary Biology
Rex Short	ISSE
Daniel Siksay	ISSE, East Tennessee Clean Fuels
Charles Sims	Economics
Kidambi Sreenivas	Mechanical Engineering, UT Chattanooga
Sheila Webster	ISSE (retired)
Christopher Wilson	Civil and Environmental Engineering
Catherine Wilt	Institute for a Secure & Sustainable Environment
Janet Wu	Electrical Engineering & Computer Science

Post Docs and Graduate Students Involved in ISSE Research

Graduate Students	Department
Benjamin Abban	Ph.D., Civil & Environmental Engineering
Sarah Eichler-Inwood	Bredesen Center
Taylor Blackstone	MS, Civil & Environmental Engineering
Jamie Campbell	MS, Information Sciences
Thomas Epps	MS, Civil & Environmental Engineering
Jennifer Erwin	Ph.D., Social Work
Aubrey Fine	Ph.D., Biosystems Engineering & Soil Science
Adrian Gonzalez	Ph.D., Civil & Environmental Engineering
David Grant	MS, Microbiology
Emily Isaacs	MS, Public Administration
Cyrus Jedari	MS, Civil & Environmental Engineering
Bernard Knueven	Ph.D., Industrial and Systems Engineering
Katherine Manz	Ph.D., Bredesen Center
Amelia McIlvenna	Ph.D., Industrial and Systems Engineering
Joy Mondal	MS, Biochemistry & Cellular and Molecular Biology
Ola Noras	MS, Biochemistry & Cellular and Molecular Biology
Brodget O'Banion	MS. Microbiology
Yasin Rabby	MS, Geography
Mohammad Ramshani	MS, Industrial and Systems Engineering
Sally Reamer	MS, Civil & Environmental Engineering
Megan Stallard	Ph.D., Biology, Middle TN State
Clifford Swanson	MS, Civil & Environmental Engineering
Varisara Tansakul	MS, Industrial and Systems Engineering
Andrew Tirpak	Ph.D., Civil & Environmental Engineering
Andrew Veeneman	Ph.D., Civil & Environmental Engineering
Eve Whittenburg	MS, Public Administration
Micah Wyssmann	Ph.D., Civil & Environmental Engineering
Post-Docs	
Ghaneeizad, Seyed	Civil and Environmental Engineering

Undergraduate Students Involved in ISSE Research

Undergraduate or Hourly	Department
Rena Abdurehman	Biochemistry & Cellular & Molecular Biology
Laurel Christian	Civil and Environmental Engineering
Andrew Dacus	Civil and Environmental Engineering
Ethan Deakins	Industrial and Systems Engineering
Caroline Jones	Civil and Environmental Engineering
Brandy Manka	Civil and Environmental Engineering
Jon Nguyen	Biochemistry & Cellular & Molecular Biology
Nicholas Pettit	Civil and Environmental Engineering
Cassidy Quistorff	Civil and Environmental Engineering
Caroline Stephens	Civil and Environmental Engineering
Leah Stephens	Engineering

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Tennessee Water Resources Research Center (TNWRRC)

(Team: Thanos Papanicolaou, Director; and Timothy Gangaware, Assistant Director)

A note from the TNWRRC Director, Thanos Papanicolaou—

During 2017-18, the Tennessee Water Resources Research Center (TNWRRC), under the leadership of Director Thanos Papanicolaou and Assistant Director Timothy Gangaware, continued supporting five on-going water resource projects funded through the USGS 104(b) program and awarded three new projects under this program.

TNWRRC continued to conduct training programs in erosion prevention and sediment control around the state. Its Level 1 course (fundamentals) was conducted 14 times and attended by 1,260 people. Its Level 2 course (design principles) was conducted five times and 186 persons attended. The Level 1 one-day recertification course was held 16 times and attended by 1,130 people. The hydrologic determination training program had approximately 75 attendees and the refresher course had 66 attendees.

The TNWRRC is expanding into the local communities to help them with water related issues. The latest effort is with the Town of Farragut. The TNWRRC and the Town are working together to identify, locate, and assess the different stormwater structures that are owned by the Town. The project is a multi-year, phased effort that will canvas the different residential communities in Farragut. The team of Thanos Papanicolaou, Christopher Wilson, and Tim Gangaware are canvassing the neighborhoods of Farragut, mapping the different assets and assessing their condition. They will compile GIS maps for the Town and a detailed report. Not only is this work mandated for maintaining the Town's MS4 permits, but also it will lead to the development of a stormwater infrastructure improvement plan.

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USGS Projects

The TNWRRC is one of 54 state-level Water Resource Research Institutes of the US Geological Survey (USGS) and administers several state-level grants through the 104(b) program. Active projects during this reporting period are discussed below.

Evaluation of Fecal Indicators and Pathogens at Recreational Beaches in Central Tennessee

(Team: Frank Bailey and Megan Stallard, Biology Department, Middle Tennessee State University)

Statement of Critical Regional or State Water Problem(s): Beach sand contact has been implicated as a potential health risk to beach goers due to presence of fecal bacteria, viruses, and associated pathogens, but no federal criteria have been developed for fecal pathogens in sand. Most research on this topic has focused on investigating the presence of fecal indicators and pathogens in beach sand from coastal and Great Lakes locations, while research at other inland recreational beaches are less represented in the literature. To our knowledge, there is no regular monitoring of fecal pathogens at recreational beaches in Tennessee (TN), and there has been very little research on this topic in the state. This research project will benefit state and federal regulatory agencies by providing data on the presence, abundance, and source(s) of fecal bacteria, viruses (coliphages), and other pathogens at inland freshwater recreational beaches in TN. The knowledge gained can potentially be applied to improve the understanding of fecal indicators found at inland beaches elsewhere the U.S. and inform regulators as they make decisions about formulation of regulatory criteria for fecal pathogens in beach sand.

Statement of results or benefits: This research will provide data on the presence of fecal bacteria, viruses (coliphages), and other pathogens at inland freshwater recreational beaches. Both traditional fecal indicator bacteria (E. coli) and alternative indicators (Bacteroidales and coliphages) will be assessed, thus assisting regulators in choosing the most appropriate and cost effective indicator for public health. Data from Bacteroidales qPCR assays will shed light on whether sources of fecal contamination originate from human waste and detection of coliphages may provide an estimate of the survival of enteric viruses. This project will also provide data on Staphylococcus aureus and methicillin-resistant Staphylococcus aureus (MRSA) numbers, which are lacking from freshwater beaches. This will give important data on the presence of non-fecal pathogens and antibiotic resistant organisms at freshwater beaches. The results from this project will have potential implications for both environmental and human health protection and will provide preliminary information in the likely event regulatory criteria are developed in the future for fecal indicators in sand at beaches. From a research standpoint, this will fill a knowledge gap in the literature regarding fecal contamination in sand and water from inland freshwater recreational beaches. Data will be disseminated through publication of peer-reviewed manuscripts and presentations at regional (e.g. TN section of American Water Resources Association) and national scientific meetings (e.g. University of North Carolina Water Microbiology Conference). This information will also be distributed to water quality stakeholders interested in recreational beach health (e.g., Tennessee Valley Authority, the US Army Corps of Engineers, and the Tennessee Department of Environment and Conservation).

Nature, Scope and Objectives of project, including a timeline of activities: Based on a report conducted by the U.S. Census Bureau, approximately 59 million people visited a beach in 2010. Beach water quality monitoring in coastal and Great Lakes states is mandated under the Clean Water Act. In this monitoring, the potential presence of fecal pathogens and associated health risk is typically monitored by enumerating easily culturable surrogate (non-pathogen) fecal indicators in water samples (e.g. Escherichia coli or enterococci). However, even though sand contact has been implicated as a potential health risk to beach goers due to the presence of fecal bacteria, viruses, and associated pathogens, beach sand is typically not monitored and no federal regulatory criteria have been developed for fecal pathogens in sand. Most

research on this topic has focused on investigating the presence of fecal indicators and pathogens in beach sand from coastal and Great Lakes locations, while research at other inland recreational beaches are less represented in the literature. To our knowledge, there is no regular monitoring of fecal pathogens at recreational beaches in Tennessee (TN), and there has been very little research on this topic in the state. Previous research in our laboratory in summer 2015 at one of the proposed sampling sites showed relatively high concentrations of E. coli in both wet and dry swash zone sand at Cedar Creek Recreational Area, a freshwater recreational beach at Old Hickory Lake in central Tennessee (see Table 1; unpublished data).

Table 1. E. coli (MPN/100g) detected in sand cores from Cedar Creek Recreational Area in TN

	Min	Max	Average
Dry sand (foreshore)	*8.3*	*14,440.8*	*1,982.3*
Wet sand (intertidal)	*8.3*	*1,258.3*	*218.7*

In fact, these data demonstrate that the highest concentration of E. coli at this site are in the samples closest to shore (Figure 1B) and in the top 10cm of the sand (Figure 1A) where children and others often play and dig in the sand.

Escherichia coli is the primary traditional fecal indicator bacteria (FIB) used by regulators to assign impairment to recreational water bodies (freshwater). One drawback to use of E. coli as an FIB is its ability to multiply in the environment outside of the host gut and lack of source specificity. Because of this, the USEPA has recognized other promising alternative indicators of fecal pathogen impairment with minimal replication outside of the gut, such as anaerobic fecal bacteria in the order Bacteroidales and viruses that infect fecal coliforms, known as coliphages.

Fecal bacteria in the order Bacteroidales are obligate anaerobes that are specific or selective with the digestive system of their host making them particularly useful to determine both the sources and amount of recent fecal contamination. Both general Bacteroidales 16S rRNA markers, and those specific for human or other animal hosts, have been developed for use in quantitative polymerase chain reaction (qPCR) assays to rapidly determine sources of fecal bacteria or concentrations of Bacteroidales in general. A quicker turnaround time to achieve results with these assays compared to E. coli culture methods minimizes the time needed for water quality regulators to make informed public health decisions for beachgoers.

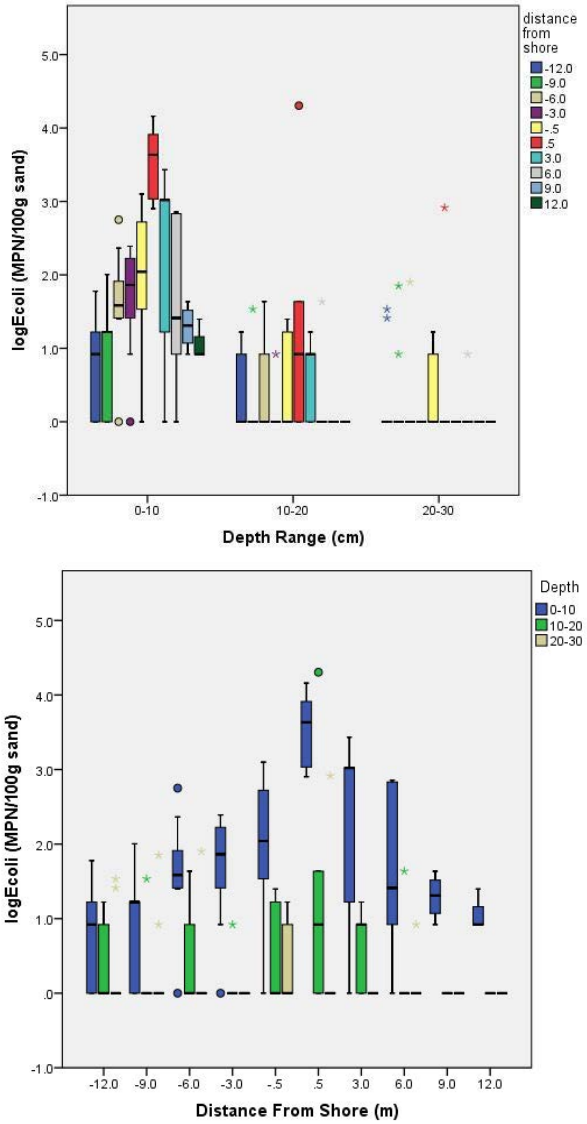

Figure 1A and 1B: Escherichia coli concentrations in sand cores from Cedar Creek Recreational Area in Tennessee

Enteric viruses are suspected to be the cause of nearly 50% of waterborne gastrointestinal illnesses. Among the leading culprits are human noroviruses, adenoviruses, rotaviruses, and hepatitis E viruses. Because of the differences in response

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to wastewater treatments, traditional FIB are not adequate indicators of viruses. Unfortunately, infectious viruses are difficult and expensive to culture and can take up to a week or more for results. The EPA recently performed a literature review to assess coliphages as primary indicators of fecal pathogen contamination and enteric viruses. Many authors recommended the use of somatic and F+ coliphages as indicators of infectious viruses for water quality. Coliphages, both somatic and F+, share similar morphology and responses to treatment as several types of infectious human viruses. Pricing and the difficulty level of culturing coliphages is competitive with the current primary FIB, E. coli, and coliphages have shown to have strong correlation with FIB and enteroviruses in water used for irrigation. According to U.S. EPA 2016 Coliphage Experts Workshop, coliphages can be used to evaluate wastewater treatment processes and disinfection efficacy and participants in the workshop agree that coliphages should be used as measured indicators in epidemiological studies.

Staphylococcus aureus at beaches have been associated with community acquired GI illness as well as skin, ear, and eye infections. While S. aureus is not typically a fecal pathogen, it is an opportunistic pathogen carried by 20-40% of people. Therefore, it is not surprising that Staphylococcus aureus and methicillin-resistant S. aureus (MRSA) are shed by swimmers and both are found in beach sand and water. It is also of note that the methicillin resistance gene from MRSA (mecA gene) can be transferred horizontally from MRSA to other live bacteria increasing levels of antibiotic resistant bacterial strains.

The proposed project will address the following research questions at two Tennessee recreational beaches, with the goal of improving the understanding of fecal indicators found at these sites. The knowledge gained can potentially be applied to improve the understanding of fecal indicators found at inland beaches elsewhere the U.S. and inform regulators as they make decisions about formulation of regulatory criteria for fecal pathogens in beach sand.

(1) How abundant are fecal indicators and other pathogens in sand and water at two freshwater recreational beaches in Tennessee?

(2) Do human feces contribute to the fecal indicators found at these sites?

Specifically, the proposed research objectives are to:

(1) compare levels of fecal indicators in beach sand between two recreational beaches on different rivers—Cedar Creek Recreational Area on Old Hickory Reservoir and Barton Springs Recreational Area on Normandy Reservoir;

(2) measure E. coli, Staphylococcus aureus, and methicillin-resistant S. aureus (MRSA) concentrations in water and the first 10 cm of swash-zone beach sand;

(3) screen for presence of human fecal pollution using qPCR (HF183 Bacteroides 16s rRNA genetic marker); and

(4) measure coliphage (viruses that infect fecal coliforms) concentrations in water and the first 10 cm of swash-zone beach sand.

Table 2. Timeline of project activities

Late May – early September 2017	September – December 2017	January – February 2018
--Water and sand sampling --Culture based assays for E. coli, coliphage, S.aureus and MRSA	--Processing PCR samples for HF183 (Bacteroides), S. aureus, and MRSA --Data analysis	--Report writing --Manuscript preparation for publication

Progress to Date: The first sampling event for the project occurred on 5/28/2018 at two freshwater recreational beaches in central TN. Sand samples were taken at 10 locations at each beach and water samples were taken at three locations at each beach. Initial sampling results show every beach sand and water sample to contain E. coli. The E. coli concentrations ranged from 20 MPN-1,989 MPN/100g for swash zone sand, but most sand samples contained less than 400 MPN/100g. Water E. coli concentrations ranged from 18.5 MPN/100mL to 90.8 MPN/100mL. MRSA was found in all sand samples with concentrations from approximately 120 CFU/100g to

too numerous to count (TNTC) and in water from 56 CFU/100mL to TNTC. Ongoing qPCR will be used to verify the identity of MRSA on selective agars. These results show the presence of fecal bacteria and pathogens at these two freshwater sandy beaches and demonstrate a potential risk to beach goers that will continue to be investigated throughout the summer.

Five more sampling events will take place during the summer, including one on Independence Day and one on Labor because these are known to be high traffic days at the beaches. Any qPCR analyses that are not completed during the summer will be completed September-November 2018 and report and manuscript preparation will take place December 2018-February 2019.

Sediment Source Tracking in Urban Watersheds: An Application in the Second Creek Observatory

(Team: Jon Hathaway, Thanos Papanicolaou, and Christopher Wilson, Civil and Environmental Engineering, University of Tennessee)

Introduction: As urbanization spreads throughout Tennessee, the effect of land use change becomes evident in the form of increased stormwater runoff, pollutant export, and stream degradation. Numerous studies have been performed to better understand these effects and develop methods for their amelioration, but gaps in knowledge still exist. Although the field of urban hydrology is relatively mature, the same cannot be said of urban water quality modeling. Recent studies have shown that current models of sediment export from urban watersheds do not perform well, necessitating new approaches to improve these models. These efforts are hampered by the high spatial variability of land uses in these watersheds, as well as the presence of stormwater conveyance infrastructure which greatly influences system connectivity and conveyance. All these variables lead to difficulty determining sediment source areas for individual storm events.

However, sediment source tracking holds promise to aid in understanding these processes. Sediment tracking methods are an established tool for determining sediment source areas, but they have been rarely applied in urban systems. The objective of this research is twofold; (1) to better understand the sources of sediment in an urban watershed in Tennessee to inform management strategies and develop a methodology for similar studies elsewhere, and (2) to use this initial study as a way to develop new hypotheses for improving water quality modeling in urban watersheds.

Methods, Procedures, and Facilities: This study will leverage infrastructure within the Second Creek (SC) Observatory which was made possible, in part, through past USGS 104B funding. The site's proximity to the John D. Tickle Engineering Building allows excellent access for sample collection and maintenance of the station. Due to the complexity of urban watersheds, this pilot study will identify one smaller catchment within the SC where the sources of sediment can be carefully identified, characterized, and tracked.

Three rainfall events will be targeted for analysis. A combination of naturally occurring radioisotopes and artificially tagged particles with Rare Earth Elements will be applied to different land covers within the smaller catchment, including parking areas and surrounding open space. At the catchment outlet, high frequency collection of sediments will capture the tagged material that is delivered to SC through the stormwater infrastructure. These samples will be transported to the University of Tennessee Hydraulics and Sedimentation Laboratory (HSL) where they will undergo isotope analysis. Using the isotope analysis from the source locations, a mixing algorithm will be applied to the event samples to better understand the source distribution present in the samples and how that distribution changes throughout the storm. That is, the most likely sources of sediment will be determined for each event.

Progress to Date: A small urban catchment feeding to SC on the University of Tennessee campus has been selected for the project and initial field investigation of the stormwater infrastructure in the area has been performed (Figure 1a). Watershed analysis suggested the primary contributing

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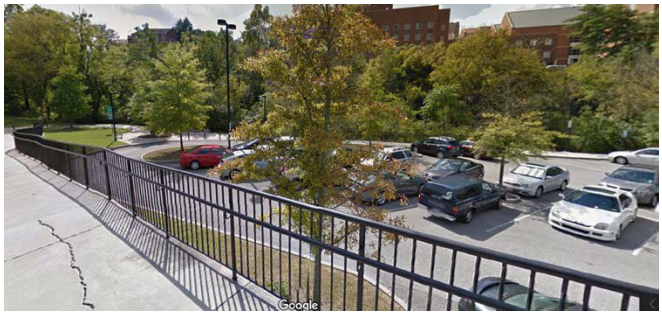
areas to the point of discharge include a parking lot, concrete pathways, and turf/landscaped areas.

Additionally, the methodology for the project has been refined to determine which tracers should be used and where they should be placed in the catchment. Figure 1b shows the primary tagging areas which feed directly to the underlying stormwater infrastructure. The stormwater runoff feeds to a single outlet (Figure 1c) where an autosampler will collect samples every 5 minutes. A time-lapse camera will be used to capture images of the outflow. Image analysis will be used to estimate the flow rate.



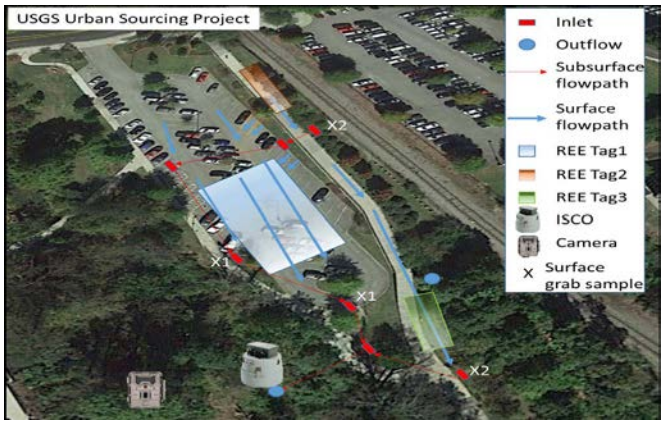


Figure 1a, 1b, and 1c (from top): Catchment Selected for Study Near UTK Campus

Conference Presentations Delivered: A presentation is planned for the 2019 Tennessee AWRA meeting.

Pending Publications: A publication is planned for this work, but a publication venue has not yet been selected.

Characteristics of Fine Sediment Embeddedness: Towards Understanding Drainage Network Lags

(PI: John Schwartz, Civil and Environmental Engineering, University of Tennessee)

Statement of Critical Regional or State Water Problem: The State of Tennessee contains many water bodies that have been identified on the 303(d) list as impaired or threatened, by which they do not meet designated beneficial uses including biological integrity [40 CFR Part 130; TCA §69-3-101 and TDEC Rules Chapter 1200-4]. A majority of streams listed are impacted by excessive sedimentation in channels causing physical habitat degradation, which reduces biological integrity. The Tennessee Department of Environment and Conservation (TDEC) is required by statutes to produce total daily maximum loads (TMDLs) for 303(d) listed streams impacted by siltation and habitat alteration. Understanding the biophysical dynamics of fine sediment infusion into the streambed gravel is critical to enhancing management and restoration strategies for impaired streams. Tennessee is not the only state facing this environmental issue with the need to improve the biological integrity of impaired streams. Many states need better assessment techniques to effectively develop siltation and habitat alteration TMDLs that identify physical and ecologically limitations in human-dominated watersheds.

Statement of Results or Benefits: The expected outcomes of the proposed research include a statistically significant response that biofilms play a key role in embeddedness, embeddedness quantified by a McNeil sampler will be correlated to TMI scores and directly correlated with biological impairment, and development of a relationship of fine sediment influx into a gravel matrix, used towards predicting embeddedness in streams.

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Development of this relationship will include variables on stream flow and suspended sediment transport dynamics. Results can potentially be used in the CONCEPTS model. Overall, a better understanding of the biophysical characteristics of stream embeddedness will allow for improved assessment methodologies of fluvial conditions, which can be applied to watershed management strategies for ecological restoration.

This research will be conducted by an undergraduate (UG) researcher, promoting undergraduate education at the University of Tennessee. In addition, the collaborative interactions with the Czech Technical University (CTU) will promote the future international research with the aim to further our research under a National Science Foundation (NSF) Partnership for International Research and Education (PIRE) grant. We also plan to work with Dr. Eddy Langendoen at the USDA National Sedimentation Laboratory using CONCEPTS, but other models and modelers will benefit from the basic data we propose to collect. The main benefit of this proposed work is to begin field data collection that matches data collected by research colleagues at the CTU. Needed for a PIRE proposal is demonstrated collaboration between the international and American universities. Collaboration between UTK and CTU will also benefit the State of Tennessee by the technical transfer of modeling techniques and sediment monitoring.

The UG student researcher will draft one or two manuscripts for publication. He/she will receive a grade in CE409 for their effort on the project.

Nature, Scope and Objectives of Project: The objectives of the research project are: 1) to improve our understanding of the biophysical processes associated with fine sediment embeddedness in the surficial (active) layer of stream channel alluvium; 2) explore how fractional transport mobility of fine sediment (silt-clayorganics) and associated embeddedness processes can be better incorporated into an existing sediment transport model, i.e., CONCEPTS, and 3) collaborate with Dr. Tomas Dostal at the CTU in order to build on our existing research with the goal to submit a NSF PIRE proposal in 2018-2019. The requested funds are essentially seed money to better position a UTK research team to win a NSF PIRE grant. Objectives 1 and 2 will be accomplished supporting an UG research student, where he/she will be enrolled in CE409, UG Research Projects. Because this proposed research is to initiate some research promoting collaboration with the CTU, and that it will be supporting the UTK ORE UG research initiative, its scope is not at a doctoral level. Though the goal will be for the UG researcher to produce a draft journal manuscript, or at a minimum generate data that can be used in a future publication. This proposed research for a USGS 104b grant aims to make progress on objectives 2 and 3 (tasks) above, collecting fine sediment data in a local catchment, and focusing on one aspect of this spatially and temporally complex problem with catchment sediment transport and in-channel retention processes.

Timeline for Activities: Collaboration between Dr. John Schwartz (UTK) and Dr. Tomas Dostal (CTU) will occur throughout the project period (April 15, 2017 through February 28, 2018). The undergraduate research will be conducted during the summer 2017 from May 15, 2017 through August 15, 2017.

Methods, Procedures and Facilities: The first task by the UG researcher will be to conduct a thorough literature review on fine sediment embeddedness, including relevant articles on sediment transport modeling. The second task for the UG student researcher will be to conduct two field studies. The first study will be to collect sediment samples at riffles where TDEC has benthic macroinvertebrate index (TMI) data. TMI data collected will be no older than 2-3 years. Sediment samples at riffles will be collected by use of a McNeil sediment core sampler, a unique sampler to collect fine sediment with the course size fractions. Particle size distributions (PSD) will be performed on the course and fine particle fractions. The fine particle fractions will be determined by the standard hydrometer method. In addition, the fine particle fraction will be dried, and using standard methods an inor-

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ganic/organic ratio will be determined. Gravel materials will be washed with laboratory DI water to obtain the organic content adhered to the course material. PSD and the inorganic/organic data will be statistically corrected with the TMI scores. The biofilm organic mass on the course material and within the fine sediment content will be estimated and normalized by weight to sampled streambed alluvium. The second experimental design is to place "boxes" of clean river rock with known D50 and overall porosity, and bury it level with an existing riffle bar structure at a location on Fourth Creek (Knox County, TN). We will let the "box" be exposed to varying flood flow stages in which we collect fine sediment in transport and record the discharge hydrograph. Fine sediment transport over the hydrograph will be estimated with use of a turbidity probe and a multi-stage siphon sampler. The analysis will examine the temporal dynamics of fine sediment flux into the clean gravel interstitial and correlate the sediograph patterns (flux dynamics) with mass transfer into the gravel "box". The number of flood events sampled will be dependent of environmental conditions. The UG student researcher will contact Dr. Eddy Langendoen at the USDA National Sedimentation Laboratory and discuss how the silt-clay size fraction is modeled in the CONCEPTS model, and how the flux dynamics measured in the above described experiment can be incorporated into the model.

Related Research: Embeddedness is defined differently between the physical and biological scientists. Physical scientists have long known of this process, and it has been termed as armouring. In the earlier work, it was observed that sand embedded between voids within the gravel matrix increased critical shear stress for incipient motion. Lee and Odgaard (1986) developed a simple model for the exchange of grain sizes between the surface and subsurface layers and associated simulation with the temporal variation observed with sediment transport rates. Curran and Wilcock (2005) developed a gravel-sand mixture bedload sediment transport relationship, which was incorporated in the BAGS model. Biological scientists have also long known about the impacts of fine sediment embedded into gravels, with the original work completed in the Pacific Northwest streams related to salmonid spawning redds. Schwartz et al. (2011) conducted an analysis of the impacts of episodic fine sediment transport on fish assemblages in the Great Plains Region of the US. In addition, Schwartz et al. (2008) developed a unique statistical procedure to characterize fine sediment transport and its potential impact on aquatic biota. More research is needed on the dynamics associated with fine sediment retention in streambed alluvium during episodic events; in addition to the influence of biofilms on those dynamic processes.

The research supports current research at the CTU where Dr. Josef Krava, Dr. Tomas Dostal and other faculty which modeled sediment yields from all sub-catchments within the Czech Republic. The project was an enormous effort on their part. They used the WATEM/ SEDEM model and calibrated it using 9,890 reservoirs from a database of 20,477 reservoirs (GIS spatial information taken from DIBAVOD). This watershed model utilizes a distributed approach, similar to USDA models SWAT and AnnAGNPS (Van Rompaey et al. 2001). Sediment trap efficiencies for the reservoirs were estimated utilizing the Brune curves method readjusted by Dendy and Champion (1978). Reservoirs with known construction dates and bathometry were measured for sediment deposition for verification. The initial national effort was to identify high yield sub-catchments for agricultural management. The WATEM/SEDEM model defined spatial patterns of erosion and deposition among the sub-catchments with the topography and land-use data being sufficient. However, estimating actual sediment transport flux were uncertain where CTU researchers recognized that their calibration procedure needed improvement incorporating stream channel erosion and sediment transport processes.

The CTU research team is interested in improving their national modeling results for subcatchment sediment yields incorporating channel processes and sediment transport, erosion and deposition.

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They have submitted a proposal to their national research agency (Czech's NSF equivalent) for the Czech-American Scientific Cooperation Program. UTK's role on the proposed CTU research is to: 1) contribute to modeling with a focus on sediment sources and transport processes associated with the stream channel utilizing the USDA National Sedimentation Laboratory's Conservational Channel Evolution and Pollutant Transport System (CONCEPTS) model; 2) conduct statistical analysis of episodic sediment transport utilizing existing datasets from CTU and UTK; and 3) pursue collaborative research funding with preparation of US grant proposals to further advance the objectives of the proposed research.

Progress to date: To date, nine streams have been selected to samples bed sediments using a McNeil sampler, in which the samples will be analyzed for particle size distributions and the percent organic matter. A student has been assigned to the project, his name is Nicholas Pettit. He will be completing the field work during the 2018 summer period. Equipment has been organized for the field work. In addition, in-situ sediment collection chambers have been designed and the Civil Engineering Department shop is constructing them. Nicholas has also started his literature review on embeddedness studies to summarize the different methodologies others have applied to quantify embeddedness.

Examining Sediment Rating Curve Hysteresis with State-of-the-Art Sensors

(Team: Thanos Papanicolaou, Jon Hathaway, and Christopher Wilson, Civil and Environmental Engineering, University of Tennessee, Knoxville)

Introduction & Problem Statement: Streams are the receptor, conveyor and transformer of terrestrial sediments. Geomorphologists quantify the sediment yield moving through the streams to examine the effects of sediment loading on the riverine channel responses and fluxes. However, sediment moves through the channels in a series of steps. It can end up spending long periods sitting on the bed, bars, and floodplains. Additionally, the transported sediment is a combination of bed load, suspended material, and fine-grained wash load. The coarsest sediments are transported as bed load, rolling and bouncing close to the river bed. Finer sediment fractions are lifted off the river bottom by turbulence and become the suspended load. The wash load consists of sediments that are sufficiently fine-grained that the river is able to transport them at uniformly high concentrations and at nearly the same rates as the water flow itself. The ranges of sediment grain sizes that are transported instream in the three modes are governed by the stream-flow velocity and by the settling velocities of the grains. These challenges can make it difficult to quantify sediment yields because they lead to a hysteresis that exists between water discharge and sediment transport fluxes. This hysteresis is more pronounced in reaches with hydraulic structures, which act as obstructions to the flow. Considerable strides have been made, though, in the last few decades that have resulted in several analytical and empirical formulations for developing rating curves to quantify sediment yield.

Methods, Procedures, and Facilities: In this study we are monitoring sediment movement by tagging sediment particles with miniature Radio Frequency IDentification (RFID) sensors. We are combining this information on sediment transport flux timing with the flow discharge hydrographs to resolve phase-space relations between water and sediment for the rising and falling limbs of the hydrograph.

The RFID technology incorporates transponders that mimic the different sediment sizes and can communicate wirelessly with a base station. The transponders are sealed in carefully drilled particles with diameters and proportions matching the field sediment size distribution. Each transponder has a unique identification number and is being tested in the laboratory, for assessing their accuracy through video observations of the sediment particle movement. The laboratory tests are conducted in a 2-m x 3-m testing box filled with sediment material.

Following the laboratory testing, the RFID system will be installed at the Second Creek, a coarse-

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grained stream on the University of Tennessee, Knoxville campus. Subsequent periodic surveys conducted throughout the year will provide the transport characteristics of the tagged sediment for variable flow discharges.

Progress to Date: To date, two types of spherical particles have been created to house the transponders, namely a glass particle and a concrete particle coated with tungsten (Figure 1). The density of the encased particles matches the density of quartz. The glass particles were heated for 30 to 40 minutes at high temperatures (~ 600oC) in order to be drilled without cracking. After being annealed, the glass particles were carefully drilled to house the transponder. When the transponder was placed inside the glass particle, it was sealed with silicon to keep the transponder in place.

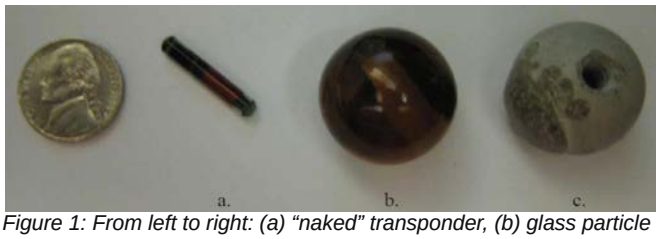

Figure 1: From left to right: (a) "naked" transponder, (b) glass particle and (c) concrete-tungsten particle.

For each type of material, the maximum detection distance was measured using a custom made excitation antenna plane. The use of a custom-made excitation antenna allows the user to increase considerably the maximum antenna-transponder detection distance. However, there is an optimum in the increase of the excitation antenna's size after which the maximum antenna-transponder detection distance can dramatically deteriorate, since more ambient noise is picked up by the excitation antenna. Currently, the transponder spheres are being tested in the testing bed filled with sediment with the custom-made antennas. Overall, the proposed research will investigate the time lag, or hysteresis phenomenon, between the sediment flux and the flow discharge, which accounts for a considerable part of the variability in sediment rating curves.

Conference Presentations Delivered: A presentation is planned for the 2019 Tennessee AWRA meeting.

Pending Publications: A publication is planned for this work, but a publication venue has not yet been selected

Combined Field Study of Turbulence and Bed Morphology in Mountainous Boulder Arrayed Streams

(Team: Micah Wyssmann and Thanos N Papanicolaou, Civil and Environmental Engineering, University of Tennessee, Knoxville)

Progress to date: The overarching goal of this dissertation research is to develop of a mechanistic bedload transport prediction model that is applicable to gravel bed rivers where ubiquitous boulders affect sediment movement characteristics. As such, a primary objective of my research, and the primary objective of this study, is to connect bedload movement observations with the complex flow characteristics that occur in gravel bed rivers. By providing improved connections of sediment movement with the driving turbulent flow forces, we are aiming to develop and improve sediment transport prediction methods. This research has implications to water problems related to the prediction of transport distances for sediment (including contaminated sediment) through complex river networks, to predicting sediment inputs into critical water infrastructure such as dams, and to the design of river restoration practices for the dissipation of flow energy and the entrapment of sediment. In this study, we planned to investigate the connections between flow and sediment movement in gravel bed rivers through the development of a field study. In the initial phases of this study, interaction with a collaborating research group in New Zealand led to a thorough review of existing literature and enabled us to pinpoint key data wherein the travel characteristics of bedload particles in gravel bed rivers was investigated. Following the findings from this effort, we decided to take a slight recourse for this project in order to develop a generic model for predicting the particle resting time of sediment atop the river bed and

investigate the connections with the driving flow forces.

The methodology employed in the particle resting time model is based on the generic spectral characteristics of turbulent flow, which is used to predict the intermittent forcing on resting sediment particles. This model is thus able to account for the most important features of the flow field in order to predict the time that sediment rests atop the river bed. Calibration and validation of the model has been conducted by utilizing identified data. Additional simulation scenarios designed to aid the development of generic particle resting time prediction tools are also a continuing effort in this project.

From this research, a conference paper was written based on the initial development and validation of the particle resting time model, which has been accepted to be presented at the IAHR River Flow 2018 conference in Lyon, France. Through presenting at the River Flow conference, we are seeking to gain further input from the research community on this topic and intend to meet there with collaborators from New Zealand in order to continue discussions about the next steps in this research. In addition, a manuscript detailing the generic resting time prediction tool for to gravel bed rivers is in preparation to be submitted to the *Journal of Hydraulic Research*.

Publications: Information in this study has been used in the following:

1. Wyssmann, M.A. and Papanicolaou, A.N. (2018). Lagrangian modeling of bedload movement via the impulse entrainment method. River Flow 2018.

2. Wyssmann, M.A. and Papanicolaou, A.N. A model for particle resting time in a turbulent open channel flow. *Journal of Hydraulic Research*. Forthcoming.

New USGS projects (March 1, 2018-February 28, 2019) awarded this reporting period:

- 2018TN136B—***Three-dimensional Modeling of river flows under extreme weather scenarios,*** Jejal Reddy Bathi (Visiting Professor) and Kidambi Sreenivas (Mechanical Engineering), University of Tennessee, Chattanooga

Abstract: The proposed research is the development and application of a 3D hydraulic and water quality model using the tool named Environmental Fluid Dynamics Code (EFDC) for City of Chattanooga (the City) urban portion of Tennessee River below Chickamauga Reservoir, TN. The developed model will demonstrate the usefulness of three-dimensional simulations for watershed management under low flow (drought) and high flow (flooding) conditions. The river historic flows will be evaluated to determine flows and river levels for extremely low (low 5%) and extremely high (high 5%) flow periods and the model will be calibrated for these extreme conditions. The calibrated model will be used to simulate water quality under varied scenarios of extreme flows so that the pollutant fate and transport, reliability and availability of flows for water supply will be evaluated. More specifically, fate and transport of pollutants entering the river system because of persistent combined sewer overflows from the City areas will be assessed in order to estimate the spatial and temporal variability of river pollution and help assist to better manage drinking water utility intake operations, which is within the proposed model domain. In addition, understanding river flows, which will be achieved by proposed model, is critical for Tennessee Valley Authority (TVA) to manage releases from Chickamauga Reservoir, which is at immediate upstream of the proposed model boundary. As well, as part of this study, potential impact on identified critical infrastructure will be determined. For example, simulated critical velocity and bed scour at the bridge piers will be used to determine stress and hence the potential damage to the bridge stability. In addition, flood inundation of the critical infrastructure along the river banks will be evaluated using model simulated flood elevation under extreme high flow conditions. Overall, the

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proposed research is a demonstration study that will showcase usefulness and approach of using 3D computer models to help prepare river watershed management to prepare for possible extreme conditions that would cause devastating damage to critical infrastructure, environment and public health, if not prepared in advance.

- 2018TN135B—***Low-cost, real time streamflow network for Falling Water River Watershed,*** Alfred Kalyanapu, Civil and Environmental Engineering, Tennessee Technological University

Abstract: Streamflow monitoring in the United States (US) is a cost-intensive venture, and usually performed by government agencies like the US Geological Survey (USGS). With reduced resources across the federal agencies towards environmental monitoring, agencies and stakeholders are challenged to respond with cross-cutting, collaborative and low-cost alternatives for streamflow monitoring. One such alternative is using low-cost environmental sensors and developing a real-time sensor network using IoT (Internet of Things) devices. With this technology, smaller watersheds (e.g., HUC-8 and HUC-10 level) can be equipped with lost-cost sensors at many locations and a clear picture of hydrological response can be achieved. Therefore, the objective of the proposed project is to develop a low-cost, real-time streamflow network for the Falling Water River Watershed in middle Tennessee region. To achieve the project objectives, the following three tasks are proposed: (i) Assemble a low-cost, real-time enabled water level sensor, (ii) Field-testing of the sensors, and (iii) lnstallation of the sensors and sensor network.

The Falling Water River Watershed, which covers Putnam, White and Dekalb counties, is home to the City of Cookeville, the urban center in the Upper Cumberland Plateau. With projected future growth, its stakeholders including the Tennessee Division of Environment and Conservation, United States Geological Survey, Tennessee Department of Transportation, Burgess Falls State Park, City of Cookeville, and Tennessee Clean Water Network, formed a collaborative partnership to develop a Falling Water River watershed plan. A crucial component of this plan is a continuous streamflow data in the watershed, which currently has one USGS station with a one-year data record. Therefore, the proposed project will lead a dense sensor network across the watershed, and over time enable the stakeholders to have a spatially variable hydrological response of the Falling Water River Watershed.

- 2018TN134B—***Rethinking bank stabilization in Tennessee to develop a classification protocol for agriculture and urbanized systems,*** Thanos Papanicolaou, John Schwartz, and Christopher Wilson (Civil and Environmental Engineering), University of Tennessee, Knoxville

Abstract: Bank stabilization in Tennessee is a concern for landowners, city managers, governmental agencies, and engineering consulting firms. Although many bank stabilization methods currently exist, the decision-making process for selecting the most optimal method has not been addressed fully due to the complex interactions between streams and uplands that are continuously changing under human modifications and climate non-stationarity. There is a critical need in Tennessee to develop a classification protocol that is science-based for selecting the most suitable bank stabilization method depending on site characteristics. This classification protocol will identify the stabilization methods that can work under the range of stream power values for a given channel reach, as well as provide guidelines to state agencies regarding the selection and placement of the possible mitigation strategies. It will also suggest the most optimal method, among those that may work, based on soil type, vegetation, environmental needs, failure risk, cost, and human disturbance, such as intense agriculture or increased urbanization.

In this study, we will take the first steps for developing a classification protocol for Tennessee by conducting an extensive literature review. The review will focus on not only the current geomorphic rapid channel assessments and available bank stabilization approaches, but also the expected ranges of stream flow conditions where these methods will work. In addition, the review will be conducted to identify potential criteria that can be used to assess bank stability. This information will go into developing a flow chart that can be used to select certain practices for a particular reach. This project innovatively uses improved assessment and evaluation techniques coupled with more quantitative parameters like stream power to identify if bank bio-based stabilitation techniques and stream restoration designs can be incorporated. As a result, this classification scheme for the state of Tennessee suggests bank stabilization methods within an ecological and geomorphic context that will result in improved ecological outcomes and at lower cost.

Training Activities

TNWRRC coordinates two statewide training and certification programs for the Tennessee Department of Environment and Conservation (TDEC). The ***Tennessee Erosion Prevention and Sediment Control Training and Certification*** program (TNEPSC) is comprised of three basic courses:

- The Level I Fundamentals of Erosion Prevention and Sediment Control for Construction Sites is a one-day foundation-building course for individuals involved in all aspects of land disturbing activities. It was offered 14 times with 1260 people attending.
- The Level II Design Principles for Erosion Prevention & Sediment Control for Construction Sites is an intensive two-day course for engineers and other design professionals focused on engineering technology needed to plan and design practices and controls for preventing erosion and managing sediment and other stormwater pollutants on construction sites. It was offered five times with 186 professionals attending.
- The Level I Recertification is a half-day course for those who have successfully completed the Level I course and need to renew their Level I certification. Recertification is required every three years. It was offered 16 times with 1130 people attending.

The ***Tennessee Hydrologic Determination Training Program*** (TN-HDT) is the second training program coordinated by TNWRRC for TDEC. The TN-HDT program consists of a three-day course designed to provide participants with a basic understanding of the underlying scientific principles, the legal ramifications, and the practical investigative techniques surrounding the determination of wet weather conveyances versus streams and other surface water features. The course was offered three times a total of 75 people attending. The state regulations that established the TN-HDT certification program require those that successfully complete the TN-HDT course attend a one-day Refresher course every three years to maintain their certification. The one day Refresher course was offered in four times with 66 persons attending.

The ***Stormwater Control Measures Inspection and Maintenance Workshop*** is a two-day foundation-building course for individuals responsible for the inspection and maintenance of permanent stormwater management practices. The course is intended for design professionals, engineers and landscape architects; landscape and other green industry professionals; and inspection personnel from all levels of government. The SCM I&M course aims to build a solid working knowledge of proper operation and maintenance of permanent stormwater measures. Topics include the permanent stormwater management requirements in the MS4 general permit; the function, inspection and maintenance of key SCMs based on the new permanent stormwater manual; and annual inspection and reporting requirements by owners/operators of permanent SCMs. The SCM

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I&M course provides a Certification with 12 PDHs upon successful completion og a short certification exam.The SCM I&M certification is valid for three years. It was offered two times with 23 people attending.

Outreach Activities

Tennessee Smart Yards

Tennessee Smart Yards (TNSY) program is jointly conducted by UT Extension and TNWRRC. Its mission is to support homeowners across the state in applying sustainable landscaping practices that are protective of Tennessee's waterways. In 2017-18, TNWRRC managed the program's communications and marketing. This included maintaining the TNSY's website, native plant database, and social media platforms; producing quarterly newsletters; updating marketing materials; and managing its office.

Watershed Symposium

The 6th Annual Watershed Symposium at UT, held September 26, 2017, was hosted by the Watershed Faculty Consortium and TNWRRC. Its aim was to provide university students an opportunity to learn a new skill with hands-on application, engage with industry and agency professionals in watershed-related fields, and participate in a problem-based Community Charrette to envision the future of the Tennessee River and its watershed. The agenda was filled with opportunities for students to engage in experiential learning with faculty from three different colleges and five different academic departments.

Over 150 students and faculty from 14 different academic units as well as university staff and invited guests attended the symposium. Opening remarks were provided by the Associate Dean of the College of Agriculture Sciences and Natural Resources, Dr. John Stier, who stressed the significance of clean water availability for successful societies and economies both in the United States and internationally. Then, two tracks of mini-workshops were available on the following topics: water quality testing for steams (instructor Dr. Joanne Logan and her assistant Natalie Landry, Knox County Stormwater), watershed delineation (instructor Dr. Joanne Logan and her assistant Forest Burks, AmeriCorps), data representation using GIS (instructor Liem Tran), rain garden design and construction (instructors Drs. Jon Hathaway and Andrea Ludwig), stream dimensioning and flow measurements (instructor Dr. John Schwartz), and stream biological sampling (instructor Dr. Brian Alford). The purpose of these mini-workshops was to deliver instruction on a diversity of specific skills used in watershed careers. A networking lunch followed in the Ellington courtyard.

Professor Brad Collett opened the afternoon session, which incorporated themes discovered through the development and experiences of his River Studio course as his students envisioned the future of the Tennessee River Watershed. Pippa Brashear, Director of Planning and Resilience for SCAPE Landscape Architecture in New York City, provided the keynote address, sharing a range of projects that she has lead for the firm, all of which melded engineering, design, societal awareness, and ecology. A crosscutting theme was the complexity of design in the context of changing climate conditions, landscape dynamics, and societal needs. This set the tone for the charrette that followed. By definition, a charrette is a meeting in which all stakeholders in a project attempt to resolve conflicts and map solutions. Students of the Landscape Architecture River Studio facilitated four interactive dialogues on the topics of Ecology and the Environment, Access and Open Space, Infrastructure and Mobility, and Economy and [re]Development. Students worked along side invited community partners to tackle these pressing issues through the unique lens of the Tennessee River corridor through Knoxville, generating a wealth of ideas and excitement for future possibilities.

Thirteen student posters were displayed as part of the annual student poster competition. The judges were faculty members Drs. Richard Strange and John Schwartz and Professor Tracy Moir-Mcclean as well as local government representative Natalie

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Landry. The "People's Choice" award went to the poster with the most votes from symposium attendees, and was awarded to Peyton Smith for her poster "Engineering Design Guidance on Highway Construction Sediment Basins," under the advisement of Dr. John Schwartz. Second place went to Kyler Hecke for his poster "Historical Occupancy Modeling of Non-Game Fishes in the Clinch River Watershed," under the advisement of Dr. Brian Alford. Third place went to Ryan Watson for his poster "Rain Gardens for Tennessee," under the advisement of Dr. Andrea Ludwig. And the first place winner was Micah Wyssmann for his poster "Modeling the Stream Restoration Impacts of Boulders: Applying the Bedload Velocity Concept," under the advisement of Dr. Thanos Papanicolaou. Throughout the day, refreshments and administrative support was provided by the Institute for a Secure and Sustainable Environment and facilitated by Tim Gangaware.

The overarching goal of the Watershed Symposium at UT is to showcase the collaborative efforts of faculty, staff, and students in the fields of watershed science and policy for the betterment of students' training in their selected field of study. Each year, the execution of the symposium changes, but the end goal remains consistent. The Watershed Faculty Consortium hosts an undergraduate and graduate intercollegiate Watershed Minor program and is committed to showing students that all societal, economic, and environmental challenges would be best viewed in the context of watersheds.

Other Activities

TNWRRC was a co-sponsor of the Tennessee Stormwater Association Annual Conference, "Streaming Together," held on October 16-19, 2017 at Fall Creek Falls State Park. Over 285 attendees including MS4 communities, state and federal government agencies and engineering consulting companies from across the State participated in the three-day event. The opening keynote speaker was Dr. Anna George, Director and Chief Research Scientist at the Tennessee Aquarium in Chattanooga, TN. The conference included over 38 presentations, a special Project WET workshop and several social networking sessions.

The Center also participated in several meetings and workshops across the state that were held to address water related problems and issues such as stormwater management, water quality monitoring, non-point source pollution, water supply planning, TMDL development, watershed management and restoration, multiobjective river basin management and lake management issues and environmental education in Tennessee.

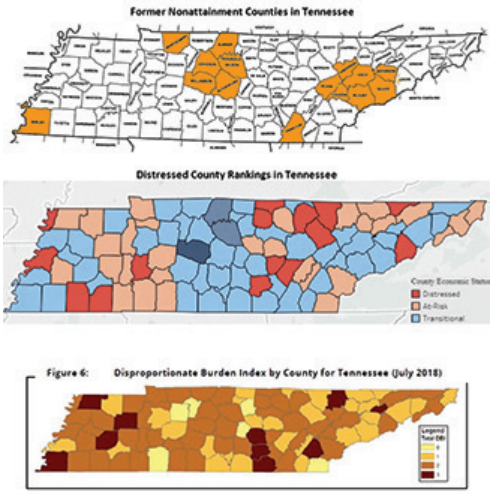
TNWRRC sponsored a webinar, held July 24, 2017, on "Exploring Regenerative Stormwater Conveyances for Tennessee: Design, Installation and Performance Evaluation." The plan is for this to be the first in a series.

East Tennessee Clean Fuels Coalition (ETCF)

(Team: Jonathan Overly, Executive Director; and Daniel Siksay, Project Manager)

Assisting TDEC with Spreading the News of VW Environmental Mitigation Trust (EMT) Funding

Over the last 1.5 years, the East Tennessee Clean Fuels Coalition (ETCF) has helped TDEC and its Office of Energy Programs (OEP) push information about this new source of funding to fleets across the state. The funds are due to the VW (Volkswagon) emissions cheating scandal and are focused on reducing nitrogen oxides (NOx) emissions, and are expected to become available in Tennessee in late fall 2018. OEP is the state-designated lead agency for administering the state's VW EMT (Environmental Mitigation Trust) allocation, which is a total of almost $46 million. We participated in in-person workshops and webinars that TDEC held last year, and held our own webinar for fleets in early 2018. We spoke with over 50 fleets directly about the funding opportunity during the last year, as well as mentioned it at many events and coalition meetings. One example fleet we worked with is Grundy County Schools. Grundy County is one of the least populated counties in the state and is situated west of Hamilton County on the Cumberland Plateau. We presented to the school board at a meeting in Coalmont, TN in summer 2018 and answered all their questions about the amount of funding they could get (75 percent of new total bus costs), the available alternative fuel buses (although their focus was mostly on propane buses that they could fuel easily at their sites), and the likelihood that their project would get funded. Along with nine other counties, they received the highest score in the index that TDEC created, called the "Disproportionate Burden Index," which takes into account percent below federal poverty level, minority percent of population, on-road NOx emissions, and vulnerable age segment percent (that includes children under 14 and adults over 65 years of age). In their case, they have a very high likelihood of winning VW EMT funding, and we put together the three



maps that are shown to help them easily understand the opportunity.

Running the Largest AFV Showcase in Tennessee's History

Beginning in 2016, ETCF started partnering with TDEC and TDOT on a fairly new Tennessee-focused event: the "Sustainable Transportation Awards & Forum." The event was first held in Memphis in 2015, then moved to Chattanooga in 2016 where ETCF joined the effort and not only helped line up some of the speakers and sessions but added to the event both an alternative fuel vehicle (AFV) showcase and evening reception. That event continued in summer 2017 when it moved to Nashville, where we pulled together the largest AFV showcase Tennessee has ever seen with 43 AFVs. The vehicles were organized into one of the Nissan Stadium parking lots in Nashville and attendees were taken on a tour of all of the AFVs at the end of the first day of the event. Then the attendees enjoyed a networking reception that was held in the Bridge Building that sits on the Cumberland River in downtown Nashville. ETCF will continue this partnership that helps us forge stronger alliances not only with TDEC and TDOT, but with fleets and other related sustainable-fleet partners across the state.

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ETCF Director Jonathan Overly of ETCF leads attendees from the Sustainable Transportation Awards & Forum event on part of the tour of the alternative fuel vehicles.

Developing Southeast Clean Cities Autogas Panel

Each year in spring, the National Propane Gas Association manages a large event that takes place typically in Atlanta called the "NPGA Southern Convention & International Propane Expo." ETCF proposed a propane autogas panel idea that was accepted and was called "Thriving: Autogas Examples from Southeastern States." ETCF pulled together coalitions from four states to present at the event on a diverse list of propane-powered fleets from across the Southeast that included street sweepers from Tennessee, Department of Corrections vans from Alabama, light-duty work trucks from South Carolina, and school buses from Florida. The panel was well received by attendees and received high marks based on content and comments from attendees. Additionally at that event, Overly was asked to speak about propane vehicles in Tennessee in a co-hosted event that was part of "The 100 Best Fleets" national program.

ETCF Goes to Washington

Most years ETCF joins other Clean Cities coalitions from across the country at an annual event that a key nationwide partner for all Clean Cities coalitions (Transportation Energy Partners) manages called the "Energy Independence Summit." Over 40 coalitions are usually represented and setup office visits with most or all of their state congressional offices. The first day of the event includes a meeting wherein congressional staff and congressmen come in and discuss alternative fuel-related legislation, and discussions and plans are made for what we will speak about with our congressional representatives in the direct meetings. The entirety of the second day is spent in meetings with those representatives and/or their key staff discussing a) what is going on in their districts and across the state with alternative fuel projects, events and fleets, and b) discussing legislation that is important to the furtherance of alternative fuels use in the USA. A key part of the second day is also supporting the national DOE Clean Cities Program (that all take place without any DOE participation) so each visit is reinforcing the good work that coalitions do across the country and the importance of the national program to all our successful efforts.

Managing "Reducing Diesel Emissions for a Healthier Tennessee" Funding to Foster Fleet Adoption of Cleaner Fuels

For the third year in a row, ETCF is managing this state EPA funding that is part of the Diesel Emissions Reduction Act (DERA) for and in partnership with TDEC. The funds amount annually to about $200,000-250,000 in Tennessee, and are to be allocated into a funding program that helps reduce diesel emissions in Tennessee and that are consistent with the national DERA program. ETCF has helped push the funding to fleets across the state, announcing it through press announcements, our own email system to about 2,000 recipients, partner connections (like TDEC's email

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system) and through social media. We have so far helped TDEC provide just over $550,000 to six fleets across Tennessee that want to adopt cleaner fuels in their fleets.

Welcoming New Staff

In fall 2017, former Project Manager Melissa Goldberg moved on to another position (within UTK) and ETCF completed the job announcement, review, and hiring process, bringing new Project Manager Daniel Siksay on board in January 2018. Daniel is off to a fast start and has been an excellent addition to the ETCF team.

Assisting & Reaching a New Type of Fleet across Tennessee – School Districts

ETCF has been in communications with about 20 school system fleet managers across Tennessee to help them understand their alternative fuel school bus options and funding that could be available to them to help offset bus costs. The funding includes CMAQ, state EPA program funds (called "Reducing Diesel Emissions for a Healthier Tennessee" that ETCF manages for TDEC) and the forthcoming VW funds. School bus fleets we have worked with include school districts in this example county list: Cocke, Sevier, Dickson, Hancock, Madison, Montgomery, Shelby, and Weakley.

While ETCF is the "East Tennessee" Clean Fuels Coalition, we work collaboratively with the Middle-West Tennessee Clean Fuels Coalition that serves the western half of Tennessee to help clients and on projects that span the entire state.

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The Methane Center

(Team: Terry Hazen, Director; and Maria Fernanda Campa Ayala, Post-Doc Assistant)

A new initiative ISSE began to develop in FY2016 is the Methane Center, whose vision is to integrate across science, engineering, and business models to create a broad conceptual understanding of CH_4 as a driver of ecosystem processes and services, and to use this understanding to create a lifecycle assessment framework for environmentally sustainable generation, management, and utilization of CH_4.

The mission of the Methane Center is to provide a continuum of fundamental and technological research advances and training in CH_4 environmental science leading to a cohort of young engineers and scientists dedicated to effective communication of meaningful scientific findings to inform and stimulate the public, and provide structured rationale for economic and environmental policy decisions and regulations.

The methane center supported two graduate students and was linked to a new seed project funded this year. The Director of the Methane Center is Terry Hazen, who has published two papers related to fracking effects and has two more under review.

A website for the Methane Center was established this year (http://isse.utk.edu/methane/).

In addition, the Center applied for an NSF grant on biocides used in fracking and their effects on microbiomes in rivers impacted by fracking. The grant was funded via a group with Juniata College and Michigan Technological University in July 2018. The UTK portion is $80K/year for three years. The Methane Center is also planning on submitting an NSF Engineering Research Center Proposal this coming year.

	Name of Stream	Temperature (C)	pH	Conductivity (µS)	Total Dissolved Solids (ppm)	Salinity (ppm)
Impacted by HF	Alex Branch	15.7	4.98	21.8	30.5	20.5
	Little Laurel	20.6	4.68	34.8	25	22.4
	UNT to Naval Hollow	14.1	5.13	22.3	15.5	14.7
Not Impacted by HF	UNT East Elk Fork	13.2	7.3	43.4	30.8	23.1
	UNT West Elk Fork	13.6	6.48	34	24.1	19.3
	Dixon Run	11.7	5.71	23.8	16.9	14.3

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Other Initiatives

The Center for Sustainable Business and Development (CSBD)

CSBD is led by Dr. Rachel JC Chen. This center was moved to Dr. Chen's home department (Retail, Hospitality and Tourism) as of June 30, 2018.

China-US Joint Research Center for Ecosystem and Environmental Change (JRCEEC)—FEWSTERN

(Team: Frank Loeffler, Microbiology; Jie Zhuang, Biosystems Engineering and Soil Science, UTIA; Gary Sayler, Microbiology (retired); and Terry Hazen, ISSE and Civil and Environmental Engineering)

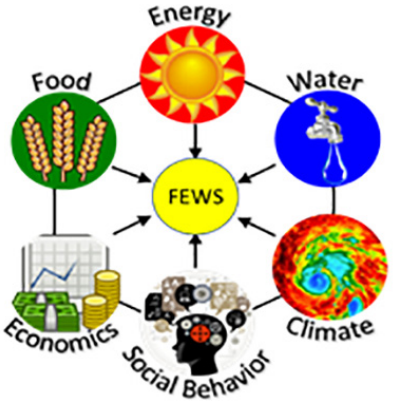
A recent award from the US National Science Foundation to faculty and scientists at the University of Tennessee (UT) and the Oak Ridge National Laboratory (ORNL) will support the development of a Research Coordination Network (RCN), designed to identify transdisciplinary research opportunities for scientists in the US and China focusing on the nexus of food, energy and water systems (FEWS). This grant, termed "Food-Energy-Water Systems Transdisciplinary Environmental Research Network (FEWSTERN)," will partner with three NSF-China awards to three teams of Chinese institutions, led by Nanjing University, South China University of Science and Technology, and Remin University of China, respectively, to develop research priorities transcending US and Chinese grand challenges.

A FEWSTERN Research Challenge Meeting, this year's JRCEEC Annual Meeting, was held December 7-9, 2017 at the Franklin Marriott Cool Springs in Franklin, Tennessee USA. This first meeting had three overarching goals:

- *Network:* Bring together experts in the areas of food, energy, and water systems (FEWS) and establish a US-China Transdisciplinary Environmental Research Coordination Network.
- *Roadmap:* Identify key FEWS research topics to address environmental problems that will challenge societies in the near future to meet FEWS goals.
- *Action:* Facilitate the building of international, transdisciplinary, collaborative research teams that identify critical research areas and prepare proposals addressing these FEWS grand challenges.

Approximately 120 US and Chinese researchers from academia, government agencies, and private industry (with expertise in food, energy, water, sociology, and policy) came together in Tennessee to identify challenges, teaming opportunities, proposal development activities, and strategic research planning initiatives.

A White Paper will be developed by Workshop leaders and several follow-on workshops will be scheduled. ISSE was a co-sponsor of this workshop.



Other Projects

Worker Health and Safety Training at Department of Energy (DOE) Facilities

(Team: Sheila Webster and Rex Short, Institute for a Secure and Sustainable Environment

In 2017-18, training was provided for DOE workers at Oak Ridge Operations, the Savannah River and the Portsmouth Sites. The training is funded by a grant from the National Institute of Environmental Health and Sciences (NIEHS) and administered by the Partnership for Environmental Technology Education (PETE).

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The use of HAZOPER ONLINE (developed by AWARDEES CCCHST and PETE) was expanded in community colleges by identification of community colleges serving areas with DOE facilities. Agreements were made with Volunteer State Community College, an OSHA Regional Center, that serves the Southeast and is comprised of several community college partners. Vol State incorporated HAZWOPER ONLINE with numerous OSHA and related Safety and Health courses that are offered on a regular basis. In addition, they are developing material for the 16-hour practical exercise to accompany the HAZWOPER ONLINE 24-hour course.

Harriman Technical Center, in close proximity to DOE facilities in Oak Ridge, integrated the 24-hour HAZWOPER ONLINE into courses for students who are completing technical training at the college. Courses include Residential/Commercial/Industrial Electricity and Industrial Maintenance Technology. If students go to work for UCOR, the 24 hours are accepted and only a 16-hour practical is required to receive the 40-hour certificate.

Participating instructors were required to complete the HAZWOPER 24-hour course before offering the course to students, as well as completing the Great EST Training provided by PETE.

To give access to business and industrial environments for applied and problem-based experience, an Instructor's Guide was developed and provided a kit of props (example equipment described in HAZWOPER ONLINE) for instructional support. Some sample activities were developed that matched selected modules. Instructors were provided with continuous technical assistance as students worked through the course.

Data was collected and analyzed on student performance, course evaluation by students, and follow-up with students and employers was done to determine how HAZWOPER content was applied in the workplace. Because the online HAZWOPER was made available to a broader audience, the result was increased numbers of participating students and an increased awareness of HAZWOPER among employees and employers.

Other activities included assistance with planning and implementing the yearly DOE Advisory Committee meeting in Portland, Maine. NIEHS provided guidance on goals and priorities. Dr. Webster and Mr. Short attended the 2018 National Trainers' Exchange in Phoenix, AZ hosted by NIH and the Western Region Universities Consortium where they conducted a session on "How to Extend and Enhance Online HAZWOPER Through Collaboration With Community Colleges, Universities, and Community Organizations."

By expanding the opportunity for training to colleges, environmental businesses, and community organizations the supply of workers eligible for employment is increasing. These workers will be prepared to improve the health and safety culture through integrated safety awareness on DOE work sites.

Rex Short at UT/ISSE booth at ETEBA conference

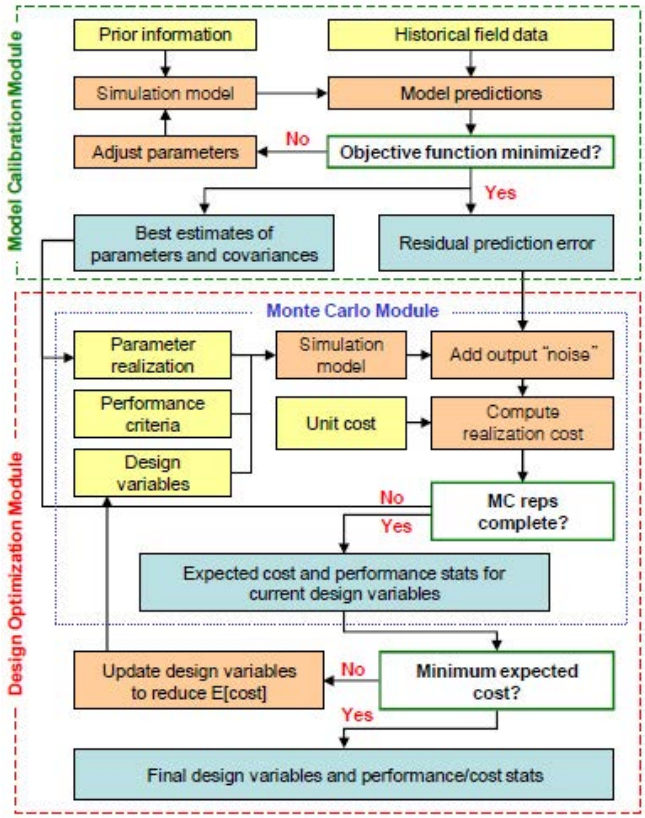
A Practical Approach for Remediation Performance Assessment and Optimization at DNAPL Sites for Early Identification and Correction of Problems Considering Uncertainty

(Team: Jack Parker, UT; and Ungtae Kim, Cleveland State University)—*Final Report*

Objective: The objective of this project was to develop and test a methodology to periodically assess and optimize remediation and monitoring strategies at US Department of Defense (DoD) dense nonaqueous phase (DNAPL) contaminated sites with remedies in place (RIP). Methods

were developed to model cost and performance of source zone and dissolved plume remediation technologies—including thermal treatment, chemical oxidation, enhanced bioremediation, and reactive barriers—and to optimize system operation and monitoring to meet user-defined cleanup criteria with minimum life-cycle cost, considering uncertainty in performance predictions using a stochastic optimization approach. Physical, chemical and biological processes expected to significantly affect performance are incorporated in the model, including effects of back-diffusion from low permeability zones, such as clay layers or matrix zones in fractured rock.

Technical Approach: The capability of the Stochastic Cost Optimization Toolkit (SCOToolkit) developed under previous DoD funding was greatly extended in this project. The previous 2D contaminant transport model was rewritten simulate 3D transport with steady-state groundwater flow along linear or curvilinear streamlines with multiple DNAPL sources. A rigorous solution for



Flow chart for SCOToolkit program

resident and flux concentrations was derived and implemented that prevents physically-impossible counter-flow dispersion (which most solutions allow). In conjunction with an upscaled dispersion model, the solution enables efficient simulation of transport in dual-porosity media and associated back-diffusion phenomena.

Performance and cost functions were developed and stringently tested for thermal source reduction (TSR), source zone in situ chemical oxidation (ISCO) , enhanced source zone mass transfer, and enhanced dissolved plume bioremediation involving electron donor injection in multiple galleries. Multiple remediation technologies may be operated concurrently or serially.

Site-wide no-further-action decisions are based on statistical criteria applied to compliance well data. For example, annual average concentrations must be less than a specified probability upper confidence limit of current concentration based on an N-year regression. Termination criteria for individual remediation system components are based on component-specific performance monitoring data. For example, individual injection galleries may be shut off when the contaminant concentration is less than a value that is optimized to meet compliance criteria with minimum cost.

Source zone TSR termination decisions are commonly predicated on soil sampling data and ISCO on dissolved concentration data. We developed and tested a method for estimating average soil concentration during thermal treatment from mass recovery measurements, which was found to be more reliable and less costly than soil sampling. Incorporating soil sampling during ISCO was found to reduce errors associated with slow rebound of groundwater concentrations after treatment termination.

These source zone performance monitoring options were incorporated into SCOToolkit, which also allows source regions to be divided into treatment zones (e.g., with different estimated levels of contamination) and subdivided further into monitoring zones (e.g., for soil or water sampling, cumulative mass recovery for thermal treatment).

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Statistical criteria were developed to allow termination of individual monitoring zones, treatment zones, or the entire system with equal decision reliability at all scales. We found that optimization of performance monitoring parameters (e.g., termination criteria, number of treatment zones and monitoring zones, type and number of samples per monitoring zone) reduced expected (probability-weighted average) cost-to-complete by 5 to 15% and reduced cost 95% upper confidence limits by up to 30% compared with conventional approaches.

SCOToolkit includes an inverse solution to obtain best estimates of model parameters and their uncertainty using available field and lab data as well as prior estimates of parameters and their uncertainty. A stochastic optimization technique is used to determine optimum operational and monitoring variables to minimize the expected costs over multiple realizations of uncertain parameters and measurements.

Protocols were developed and implemented to periodically refine model calibration taking into consideration new data from monitoring, to assess the probability of the current operations to meet cleanup objectives, and to reoptimize (or redesign if necessary) remediation and monitoring variables to minimize expected cost-to-complete taking into consideration performance and cost uncertainty. Because prediction uncertainty generally decreases as additional data is used for calibration, predictions become more accurate and less overdesign is required to compensate for uncertainty. Case studies on hypothetical and field sites demonstrated that incremental re-optimization can greatly improve the likelihood of meeting remediation criteria within a target timeframe while reducing the expected cost by 10 to 20% or more over conventional approaches.

The SCOToolkit package also includes a number of Excel-based tools to pre-process data for input into calibration and optimization modules, as well as to analyze performance monitoring data to make real-time termination decisions based on the multi-scale statistical decision protocol.

Benefits: Although most DoD sites have or should soon have remedial action plans in progress, many will not achieve regulatory closure quickly. Some planned remedies will likely not perform as expected and will require modification or, in some cases, implementation of a different remedial action plan. This project provides tools to periodically assess remediation performance, identify and rectify problems, and optimize remediation operations and monitoring to minimize life cycle costs while meeting remediation objectives. By explicitly optimizing operations to minimize probability-weighted cost-to-complete taking into account uncertainty in site characterization, model predictions, and remediation technology performance, as well as measurement "noise," numerous nonlinear interactions and tradeoffs are taken into account that conventional approaches would never consider. Results indicate that average savings in cost-to-complete across all sites of 10% to 30% can be readily achieved along with substantial decreases in remediation duration.

Stormwater Goes Green? Investigating the Benefit and Health of Urban Trees in Green Infrastructure Installations

(Team: Jon Hathaway and John Schwartz, Civil and Environmental Engineering, Jennifer Franklin, Forestry, Wildlife and Fisheries; and Bill Hunt, NC State, Biological and Agricultural Engineering)

Project Summary: Trees have many important functions within the urban environment including air quality improvements, wildlife habitat, and mitigation of the heat island effect; however, their contribution to stormwater management is not well understood. The goal of this project is to demonstrate the role of trees in stormwater treatment systems in the eastern United States and beyond, and to make recommendations regarding treatment system design and tree species selection to maximize functionality and health. Tree health and function will be quantified using: (1) a field survey of existing stormwater treatment systems, (2) a laboratory experiment to compare tree performance to other types of vegetation, and (3) a field performance study of tree-specific stormwa-

ter treatment devices. Based on the results of these studies, design guidelines will be developed which explain how best to integrate trees into stormwater treatment systems.

Progress: This project is nearing completion as the Ph.D. student will be defending his dissertation in October, 2018. Of the four chapters making up this dissertation, three have either been published or are in review. The results of the project have been presented at numerous in-state and national conferences with great interest from the audience. The results of the study have shed light on the health of trees in green infrastructure systems, what properties of these systems may contribute to tree health, the contribution of trees to green infrastructure function, and the physiologic response of trees to these unique environments.

Future Plans: The project will culminate in a free webinar in early 2019 describing the results of the study, and a fact sheet developed with the Forest Service to describe how trees can be better incorporated into green infrastructure design.

Top: Andrew Tirpak describing sap flow sensor to other UT students. Bottom: Andrew Tirpak tours Forest Service staff around UT greenhouse, showing them the mesocosm experiment.

Cooperative Agreement between National Park Service and University of Tennessee: Impacts of Acid Deposition on Water Quality and Aquatic Biota

(PI: John Schwartz, Civil and Environmental Engineering)

The Great Smoky Mountains National Park (GRSM) Water Quality Monitoring Program is part of the US National Park Service 20-year Vital Signs Program and Inventory and Monitoring (I&M) network. Nationally, I&M networks prioritized research questions and monitoring data needs in the early 2010s related to: 1) focal resources important to each park, which may include individual species, species assemblages, or ecological processes, 2) agents of change or stressors that are known or suspected to cause changes in those focal resources over time; and 3) key properties and processes of ecosystem health, e.g., weather, land use patterns, water quality, soil nutrients. The GRSM Water Quality Monitoring Program was incorporated into the national Vital Signs Program in 2014, continuing the efforts that had been conducted since 1991, consisting of 1) baseflow monitoring of selected streams throughout the Park and referred to as the "Park-wide Stream Survey", and 2) hydrologic and water quality monitoring for biogeochemical studies at a long-term, high-elevation research station in the Noland Divide watershed (NDW) headwaters. Monitoring at the NDW site includes flow/volume measurements and chemical analysis of rainfall, throughfall, soil water, and stream water. Matt Kulp is the GRSM Project Manager who oversees the collaborative effort between the GRSM and the University of Tennessee. The first picture below shows graduate student Andrew Veeneman collecting data on Palmer Creek as part of the Park-wide Stream Survey. The second is a photo of our open site deposition collector and full weather station at the NDW research site.

This past year graduate students Adrian Gonzalez, Tom Zimmerman, and Andrew Veeneman worked on the project, with the undergraduate assistance from Caroline Jones. Adrian Gonzalez completed

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Andrew Veeneman collecting data on Palmer Creek in the GRSM

Open site deposition collector and full weather station at the high-elevation Noland Divide Watershed Research Site. Note: vegetation has been cleared since photo was taken for routine site maintenance.

his doctorate in May 2018 where his research examined sulfate sources and fate/transport dynamics in the high-elevation areas of the GRSM utilizing sulfate/oxygen isotope analyses. Three articles have been prepared for publication, and one was submitted to *Applied Geochemistry*. Andrew Veeneman continues with his MS degree, revising the sulfur and inorganic nitrogen throughfall deposition map for the GRSM, which has not been updated since 2000. Two new graduate students started this fall semester to continue the research in the GRSM; they include Taylor Blackstone who will be investigating ion exchanges between different forest canopies and soils, and Salley Reamer, who will be investigating changes in soil chemistry due to forest fire.

This past year, a collaboration among John Schwartz and Qiang He (CEE); Jennifer Schweitzer, Karen Hughes, and Mona Papes (EEB); and Charley Driscoll (Syracuse University) was initiated to study the environmental impacts from the Chimney Tops II (Gatlinburg) Fire on vegetation, soils, and water in the GRSM. We obtained internal funds from the FUSION program directed by Kimberly Eck in the UTK Office of Research and Engagement (ORE). In addition, ORE provided seed monies to continue this forest fire research. The goal is for our research team to prepare an NSF grant to better understand the environmental impacts of fire on forest ecosystems in the eastern United States. Most research has been conducted in the West so there is great interest to better understand the biogeochemical processes and shifts in environmental conditions from fires in eastern forests. Jennifer Schweitzer served on a special NSF panel to identify key research questions associated with fire in eastern forests.

In August 2018 as part of a Climate Adaptation Student Study Workshop organized by the USGS/North Carolina State University (NCSU) Southeast Climate Adaptation Center, John Schwartz and Jen Schweitzer assisted with lectures on air and water quality in the GRSM, and the impacts of the Chimney Tops II Fire to a group of about 15 students from NCSU and UTK. Paul Super with the GRSM also presented on science being conducted in the national park. We toured the burn area from the Chimney Tops II Fire and the NDW research site.

John Schwartz continues to work with Charley Driscoll at Syracuse University on acid deposition monitoring and modeling in the GRSM. This research has focused on determining critical loads for sulfate and nitrate deposition from atmospheric sources to protect aquatic biota. Dr. Schwartz also has worked with Barry Baldigo at the USGS New York Division to further investigate responses of the native brook trout community to stream acidity from acid deposition. Two publications were produced this past year, which are listed in this report under “Publications.”

Microgrid Optimization

(Team: Jim Ostrowski and Amelia McIlvenna, Industrial and Systems Engineering)

Summary of Progress: This work has most recently developed a novel iterative algorithm for deciding the price of electricity within a microgrid for the next 24 hours. The algorithm iterates between the microgrid side and residential home side, updating the price of electricity each iteration, until the generation and load forecasts agree. The microgrid side solves a Mixed Integer Linear Program (MILP) to determine economic dispatch of generation sources within the microgrid. On the homes side, HVAC output is scheduled while taking into account a reasonable base load for each home. It is natural that given the same price signal, homes will take similar actions such as operating their HVAC at low price. This can lead to a large peak load at times of low price. Moreover, for an iterative algorithm, these similar behaviors can cause convergence issues. To avoid load "clumping" at low prices, a perturbation was introduced so each home receives a unique price. After initialization with a 24-hour price signal, each home is assigned a randomly generated perturbation parameter within a small interval for each time period in the forecast interval. Then each home's price signal is adjusted at each iteration according to their perturbation parameters. Preliminary results show a reduction in peak load and faster convergence of the algorithm when using unique prices. Moreover, load is more distributed throughout the forecast range.

Additionally, a second microgrid side optimization was developed for integration into Oak Ridge National Laboratory's CSEISMIC microgrid controller. The controller has been deployed at a real-world microgrid located in Hoover, Alabama. The optimization solves a MILP which provides setpoints to the devices in the microgrid, while also solving a relaxed linearization of an AC optimal power flow model. The microgrid contains 60 residential homes, a 330kW PV panel, 680kW Li-ion battery, and 400kW natural gas generator. The CSEISMIC microgrid controller is currently operating the physical microgrid while using this optimization framework.

Publications and Presentations: A poster, titled "Optimization framework for microgrid control," was presented at GEM-ASEE Doctoral Engineering Showcase January 22-23, 2018. A preliminary abstract has been submitted to the Informs Computing Society 2019 meeting, which will take place next January. The talk, titled "Shady pricing: using price distortions to improve convergence in microgrid optimization," will cover the in-lab simulation of the pricing algorithm and convergence/peak load reduction results.

Future Plans: In addition to pricing algorithm simulations, the partnership with Oak Ridge National Laboratory will enable the algorithm to be tested on the physical microgrid in Hoover, Alabama. Our contribution will be integration and testing of the microgrid side optimization and price update handler. These will be deployed separately from the CSEISMIC microgrid controller. Each home will be equipped with a VOLTTRON home agent platform, which was developed at Pacificc Northwest National Laboratory and modified by the ORNL team. The price update handler will communicate with home VOLTTRONS to facilitate the algorithm (see Figure 1). The physical microgrid is currently being prepared for integration and testing of the pricing algorithm.

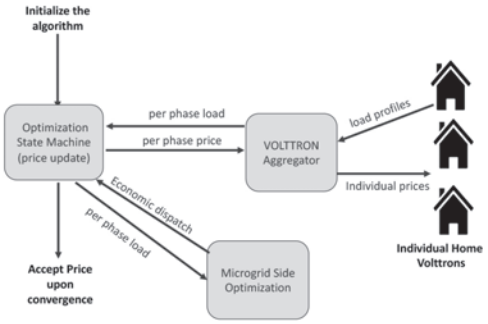

Figure 1: Flow diagram for the pricing algorithm

Stormwater Infrastructure Inventory and Mapping for the Town of Farragut

(Team: Thanos Papanicolaou, TNWRRC/Civil and Environmental Engineering; Tim Gangaware,

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TNWRRC; and Christopher Wilson, Civil and Environmental Engineering)

ISSE, the Tennessee Water Resources Research Center and the Town of Farragut are continuing with their joint effort to identify, locate, and assess the different stormwater structures that are owned by the Town. This is a multi-year project, where the TNWRRC team will canvas the different residential communities in Farragut. Last year, the team assessed the stormwater assets in the Village Green, Fox Den, and Kings Gate communities. This year, in Phase 2, the communities include Old Stage Hills, Concord Hills, and Thornton Heights. The team will map the different assets and assess their condition. In addition, they will use a waterproof snake camera to inspect the interior of the catch basin inlets, manholes, and culverts. In the end, a GIS map for the Town with all the assets will be compiled along with a detailed report. Not only is this work mandated for maintaining the Town's MS4 permits, but also it will lead to the development of a stormwater infrastructure improvement plan.

UT student and Farragut resident, Caroline Stephens, prepares a snake camera to inspect the inside of this catch basin.

Trends and Strategies for Tourism in Appalachia

(Team: Timothy Ezzell and Catherine Wilt, ISSE; Rachel Chen and Stefanie Benjamin of UT's Department of Retail, Hospitality and Tourism Management; and Mr. Bruce Decker of Collective Impact, LLC in Huntingdon, WestVirginia)

In late 2017, ISSE received a $200,000 competitive grant from the Appalachian Regional Commission—a federal economic development agency—to conduct a 16-month study on "Trends and Strategies Related to Tourism in Appalachia." This study is the largest and most comprehensive study of tourism ever conducted by the commission, which covers 205,000 square miles across 420 counties in 13 states. Through a mixed-methods research approach, the project will identify opportunities for local growth of tourism activities and promote best practices for tourism and tourism business development.

The study, being conducted through February 2019, includes the following components:

- a quantitative analysis with a thorough and robust analysis of regional, state and local data sets.
- an Appalachian Tourism Industry Survey directed at industry operators and stakeholders. The survey, sent to tourism directors, venue managers, and business owners, will help identify current and emerging trends, barriers, and potential case studies.
- an Appalachian Visitors Survey. This survey, distributed among visitors to the region, help develop an understanding of tourist's experiences and perceptions.
- five community case studies to help illustrate local tourism success stories and demonstrate best practices and effective development strategies.
- five business success stories to identify and illustrate tourism business development best practices and strategies.
- two social media case studies to illustrate exemplary and innovative social media and e-commerce strategies.
- each of the twelve case studies will include site visits, interviews, focus groups, and a local assessment.
- a thorough analysis of all data obtained during the research process and develop recommendations, strategies, and best practices for both tourism and tourism business development.

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- finally presenting these findings in an accessible and engaging project report. The team will also conduct a webinar and produce digital stories to illustrate notable case studies.

Flyer for survey

The research is being conducted by a team of researchers and practitioners with extensive experience in tourism development, mixed-methods research, and Appalachian development and policy. ISSE researchers include principle investigator, Dr. Tim Ezzell and co-principal investigator, Catherine Wilt. In addition, the team includes co-principal investigator, Dr. Rachel Chen and Dr. Stefanie Benjamin of UT's Department of Retail, Hospitality and Tourism Management and Mr. Bruce Decker of Collective Impact, LLC in Huntingdon, West Virginia. Researchers will use surveys, site visits, and focus groups as part of the research method. The researchers also will identify communities to use as case studies to illustrate local tourism success stories and best practices for tourism business development.

Overcoming Health Access Barriers in Haywood County, Tennessee

(Team: Catherine Wilt and Timothy Ezzell, ISSE)

From September 2017 through February 2018, ISSE researchers Catherine Wilt and Dr. Tim Ezzell, along UT MPPA graduate students and ETSU collaborator, Dr. Rebecca Fletcher, conducted a participatory research and planning process in Haywood County, and its county seat, Brownsville to identify potential solutions to the county's growing medical crisis. Haywood County is located along the I-40 corridor, between Memphis and Jackson. County health statistics are alarming, demonstrating lower than average access to health care, exercise opportunities, and a healthy food environment. Health access became a critical issue in the county in 2014 when Haywood Park Community Hospital closed. County residents now face an ambulance ride of an hour to Memphis or 35 minutes to Jackson for emergency medical treatment.

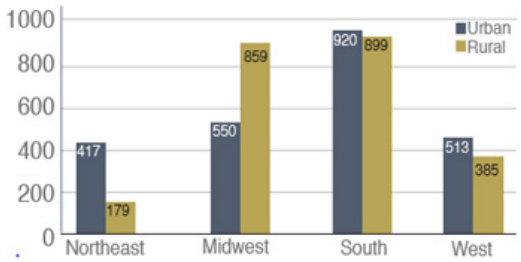

Figure 1. Number of Hospitals by U.S. Census Region and Rural/ Urban Status (2012-13)

Haywood County's hospital closure is just one of an alarming number of rural hospital closures that have occurred in the past two decades. According to statistics tracked by the Federal Office of Rural Health Policy, the United States had approximately 5,000 short-term, acute care hospitals in 2012-2013; about half of these facilities were in rural areas, with the largest number (899) located in the Southern U.S. (see Figure 1). From January 2010-January 5, 2018, 83 rural hospitals closed. Tennessee has suffered a disproportionate number of closures—ten hospitals have closed or eliminated inpatient services during that period, giving the state the second highest hospital closure rate in the country, behind Texas.

ISSE was contracted to conduct a public planning process with the community to address the following goals:

- To gain a better understanding of the health and health access issues facing Brownsville and other rural communities.
- To develop project ideas and strategies to help address these issues in Brownsville and Haywood County.
- To align these projects and strategies with other county development goals, including development of the Haywood County Megasite.
- To engage residents in this process and, by doing so, help improve local capacity to address other local issues and concerns.

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Through two public meetings and questionnaires, ISSE researchers identified five significant hurdles present in Brownsville and Haywood County, and further identified potential solutions within short-, mid-, and long-term planning horizons. The identified hurdles included:

- Learning about healthcare resources - Many residents are not fully aware of the programs and services available to them.
- Getting to healthcare resources - Some residents defer or avoid healthcare because they lack reliable and efficient transportation.
- Access to routine care - Uninsured residents may defer or avoid preventative or routine diagnostic care services, leading to more expensive treatment.
- Transportation to emergency care - Misuse of the local ambulance service for non-emergency service calls has created a lack of transportation for true medical emergencies.
- Access to emergency care - With no emergency room, county residents—regardless of insurance status—face dire risks in cases of medical crisis.

Recommendations for potential solutions were diverse. Some related to better information and communication of healthcare options, such as participating in an enhanced 211 call center. Other solutions related to transportation constraints within the rural county, such as the MyRide West Tennessee program for senior citizens, and better call screening and resident education for medical 911 calls. Finally, some of the problems of access to routine care and emergency care require developing partnerships beyond the community, such as developing clinical partnerships with higher education institutions and regional rural partnerships to develop shared policy proposals across the state.

Haywood Co. residents' statements about local healthcare

Seed Grant Projects from Prior Years

Sustainable Treatment of Wastewaters Generated during Unconventional Oil and Gas Production with Production of Renewable Hydrogen

(Team: Abhijeet Borole, Chemical and Biomolecular Engineering/ORNL; and Terry Hazen, Civil & Environmental Engineering/ISSE)—*Final Report*

Summary: Produced and flow-back water were acquired from companies involved in oil and gas production. The samples were used to provide substrate for enrichment of a microbial consortium containing electroactive organisms to enable current and hydrogen production from the organics in the fracking/produced water. Development of an electroactive microbial community to produce hydrogen from flow-back and produced water was successfully completed. Furthermore, the performance of the microbial electrolysis cell (MEC) was improved to achieve a current density > 1 A/m2 and a hydrogen productivity of 1 L-H2/L of anode volume-day. The salt and organic content of the water streams obtained from two different sites in Texas were analyzed. The salt concentrations were very high as exhibited by the high conductivity (> 100 mS/cm) and the organic content for the different samples ranged from 2.2 to 18.6 g COD/L. Microbial characterization of the produced water indicated presence of Paenibacillus sp. The electrochemical activity of the consortia was evaluated using acetate as the substrate and shown to reach a maximum current density over 11 A/m2. The configuration of the reactors and their operation had to be redesigned and reconfigured to allow processing high salt concentrations in the reactor. These included modifications to handle high concentration of divalent cations, changes in COD analysis protocol and use of alternate buffers to prevent precipitation in reactors.

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Successful demonstration of the proof of principle of microbial electrochemical technology for treatment of flow-back water was demonstrated. This indicates potential to develop practical, sustainable solutions for managing the large volumes of wastewater generated via hydraulic fracturing. Funding to continue the research and develop the technology further is being sought from NSF, USBR, and DOE.

Introduction: Wastewater is generated in large amounts from oil and gas reservoirs. On average, 10 gallons of water is produced for each gallon of oil/gas generated. The water produced from unconventional reservoirs that have been hydraulically fractured have recently gained interest due to the surge of unconventional reservoir activity in the United States. The water produced from hydraulically fractured wells can be described by the time when a well begins producing oil and gas, though oil and gas companies may not make this distinction. In this report, fluid that returns to surface before oil and gas is recovered is called, "flow-back" water. This period can last for a few days to weeks. The water generated subsequently is called, "produced water". Produced water is generated along with oil and gas until hydrocarbon production is deemed uneconomical, where the well stops producing entirely or is "shut-in." For the work proposed here, this distinction leads to important insight.

There can be a large difference in the contaminants present in the two waters. Flow-back water can contain high concentrations of organics, some of which are added during fracturing. In contrast, produced water often contains high salinity but low concentrations of organics. Beyond the differences associated with flowback and produced water, there is considerable heterogeneity in the quality of water obtained from different wells. This variability makes predictions or correlations on flow-back/produced water difficult. The work conducted in this project included both types of water, however, the flow-back water was more relevant due to the interest in generating energy from the organic contaminants.

Experimental Details: The proposed work included development of microbial consortium for treatment of flow-back and produced water. The project had two goals: (a) Enrichment of electroactive consortium to treat salt-contaminated wastewater in MEC.; and (b) Determination of hydrogen production potential and understanding the effect of salts and other contaminants on productivity.

Microbial electrolysis cells (MECs) were developed using real flow-back and produced water. The following samples were obtained from the two TX companies generating fracking wastewater used in this study.

Sample 1. The first set of produced water samples were provided by Sheridan Brewer from Dr. Hazen's lab, which came from West Texas. The organic content measured as chemical oxygen demand (COD) of the produced water was found to be in the range of 3.3, 18.6, 2.2, and 16.7 grams COD per liter (g/l). A blend of equal parts of all four samples was used in initial MEC experiments. Conductivity of the blend was found to be 176.5 mS/cm. For initial enrichment, the produced water blend was mixed with glucose and acetate at a ratio of: 1 g of acetate: 1 g of glucose: 2 g COD of produced water. After this initial enrichment, further work was carried out using a second sample of water as described below.

Sample 2. A sample of flow-back water was obtained from an oil well owner and operator based in Culberson County, West Texas. The COD of the flow-back fluid was found to be 5.13 g/l. Conductivity of the produced water was measured to be approximately 138 mS/cm. The sample was analyzed by ion chromatography which indicated presence of calcium and magnesium ions at high concentrations, in addition to high chloride and sodium concentrations. The analysis was reported previously. Part of the water was treated with sodium phosphate dibasic to precipitate and remove calcium, since it was found to hinder mass transfer in MEC. Additional Samples obtained by our lab from exploration and production companies in West TX were also used. The COD for the samples were 3.9, 0.36, 5.8, and 1.46 g/l, with

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conductivities of 136.1, 7.492, 160.1, and 90.07 mS/cm respectively.

HPLC analysis was also performed on the flow-back water, however; due to unavailability of appropriate standards, the peaks could not be identified. Microbial analysis of the produced water used in the experiments was done by Maria Fernanda Campa from the Hazen Group. The results indicated presence of a Paenibacillus sp., a genus of facultative anaerobes, which has been found to consume guar gum as a sole carbon source by at least one isolated strain. Guar gum is frequently used as a fluid thickener in hydraulic fracturing operations and serves as a carrier for propping agents.

Results and Discussion: Electroactive consortium enrichment—MECs were operated for a period over a year, using different configurations to eliminate operational problems associated with salt precipitation, low COD removal and to adapt the microbial consortia to the high salt and recalcitrant organics in the fracking water streams. While our initial goal was to pursue enrichment of electroactive community, we encountered issues where factors other than biology were limiting the performance of the anode. Mass and charge transfer issues were identified when real wastewaters with salts from the reservoir were used. Membrane fouling was one of the issues, which was managed by minimizing pH changes and reducing salt precipitation in anode. Additionally, the cation exchange membranes were replaced by anion exchange membranes to prevent fouling. These changes alleviated many of the problems, enabling the enrichment process to proceed.

Effect of organic loading rate on performance—The MECs were tested under continuous operation at two different organic loading rates to examine if a proportional increase in performance is observed. It was also necessary to find out whether the charge transfer still limited performance. It was our hypothesis that if the MEC performance improved with organic loading rate, then the AEM was not impeding charge transfer. The organic loading rate was increased from 2 gld to 4 gld. It was found that the increase in organic loading rate did increase the current density although not proportionately.

Effect of substrate concentration and mode of operation—To test if the current produced was limited by substrate availability, a batch experiment was performed on both cells with the same anode media and bicarbonate buffer. The substrate concentration was increased to 0.5 g/l in the anode media. The typical concentration in the anode at a continuous loading rate of 2 gld is 0.023 g/l. Thus, the batch experiment was conducted at roughly 21 times higher COD concentration. The results indicate that there a higher current density was obtained (over two fold) during the early part of the run, however, the overall current density was not higher than the continuous experiment. A comparison with acetate operated in batch mode showed that the performance was much higher. Since acetate is a substrate favored by exoelectrogens, it is expected to give higher performance. This was observed experimentally at a concentration of 0.5 g/L examined in the MECs (Table 1). The results reported for batch experiment with flow-back water used the water treated with sodium phosphate dibasic to remove calcium via precipitation. Examining the MEC using acetate as the substrate revealed a maximum current 3-fold higher than flow-back water. The results indicate that the mass transfer issue was resolved using the anion exchange membrane and calcium precipitation and that the system performance was now limited by the biology of the anode.

Effect of exoelectrogenic substrate enrichment on current density—Further enrichment of the consortia was conducted using a mixture of flow-back water and acetate. When flow-back water is fed to the MEC anode, the organics in flow-back water degrade to generate smaller molecules. Acetate is one of the byproducts of these hydrolytic and fermentative reactions. Current production is achieved from substrates like acetate, which are known substrates of exoelectrogenesis. Therefore, acetate was included during enrichment so the exoelectrogens can grow. Further, in order to

examine the electrochemical performance of the system, acetate was used as the substrate. The results are shown in Figure 1.

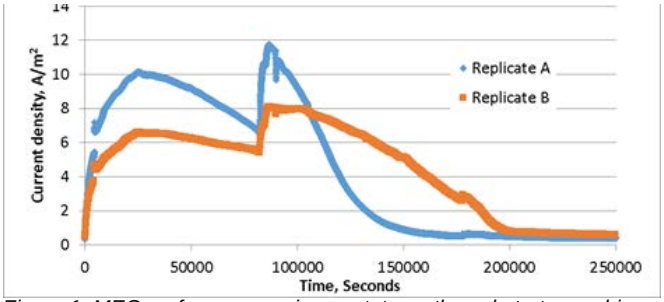

Figure 1. MEC performance using acetate as the substrate reaching 10-12 A/m2 in current density, indicating high potential for current and hydrogen production from waste streams.

- Maximum current densities reaching 10-12 A/m2 were achieved using the same MECs used in flow-back water experiments, illustrating the high electro-activity of the anodic biofilms enriched in the MEC. The lower current production in experiments where flow-back water was provided at a COD of 0.5 g/L is therefore, likely due to the limitations in initial degradation of the organic compounds present in the wastewater. The fermentative reactions can be improved by further growth of the biofilm on the organics present in the flow-back water.

Conclusion: The two primary objectives proposed for this study have been completed. Enrichment of a microbial consortium capable of using produced water or flow-back water organics as the sole source of energy for electron generation was accomplished by demonstrating current production using these conditions. Secondly, production of hydrogen was demonstrated in the MECs increasing proportionally with organic loading. The results are encouraging and represent the high performance of MECs treating produced water, which will be published as a manuscript by the end of the year.

Proposal Development Activity: Two proposals were submitted based on the results obtained in the study. One was sent to the US Bureau of Reclamation (USBR) and other to NSF. The first one was a collaboration between Dr. Borole, Dr. Hazen, and Dr. Quinn from Lawrence Berkeley National Laboratory. It was focused on treatment of salt and selenium contaminated water. The first attempt was not successful, however, the USBR Program Manager and the staff at the pilot plant at Panoche Water District indicated interest in salt removal. The reviewers recommended conducting lab-scale studies to develop the method further. The proposal will be submitted in the next round of proposals.

- A second proposal was submitted to NSF targeting salt removal from produced water. The proposal was reviewed favorably, but needed further experimental results, which are being obtained and have potential to be successful in the next round. It will be submitted again in October 2018. The PI is also working with a team of scientists interested in submitting a water hub proposal to DOE. One of the focus areas of the proposal will be produced water treatment, so the work conducted in this project will be helpful.

Enzymatic degradation of biodegradable plastic polymers by fungi and/or bacteria

(Team: Todd Reynolds, Microbiology; and Jennifer DeBruyn, Biosystems Engineering & Soil Science)—*Final Report*

Our project's goal was to characterize regulation of Poly-lactic acid degradation by two soil isolates: *Bacillus pumilus* and *Rhodococcus yunnanensis.* This project's progress has been realized in two main areas:

- Characterization of environmental conditions that promote Poly-lactic acid degradation.
- Initial characterization the proteome of extracellular enzymes produced to find and characterize unique hydrolases active against PLA.

A third area is planned for the future and will involve using transcriptomics in combination with data to explore how PLA degradation is regulated.

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Multi-scale optimization methods for electric distribution systems with renewables

(Team: Jim Ostrowski, Industrial and Systems Engineering; and Hector Pulgar, Electrical Engineering & Computer Science)—*Final Report*

There have been three main thrusts in the past year for the "Multi-scale optimization methods for electric distribution systems with renewables." They are as follows:

- Integrate a microgrid optimization model into ORNL's software for real time deployment: Ph.D. student Amelia McIlvenna is currently focusing on formulating a microgrid optimization component for a connected communities project in collaboration with Oak Ridge National Lab. The connected communities project has two major aspects: microgrid operation, and individual house operation. Oak Ridge National Lab partnered with Southern Company to run the connected communities system in two real-world communities, one of which has already been built and another of which will be built in the next year. The first community, with about 60 homes, was commissioned November 2017.
  We have completed an AC optimization framework for Oak Ridge National Lab which will return setpoints for the microgrid. For the first community being deployed, the setpoints component will take in load data, as well as parameters for a 330 kW PV unit, 100 kW and 200 kWh Li-ion batteries, and a 400 kW generator. We also take into account the network structure of the microgrid, with AC power. Because of this, the model has many non-linear constraints, which increase difficulty of the problem. Non-linear constraints were therefore linearized to decrease computational burden. As of date, the developed model has passed testing in ORNL's real time digital simulator is should be implemented in the community within the month.
  The second optimization framework was to determine the optimal three-phase balanced load for the system. Prices are decided for each phase, and sent to the homes. The homes can decide to adjust load or remain the same. If load is adjusted, price will be re-evaluated. The team has begun lab testing with the microgrid control system at ORNL. The goal of lab testing is to ensure robustness in test cases, and adequate communication of the optimization with both the homes and the microgrid control system. After successfully passing the reliability checks in the lab, it will be implemented in the community.
  ORNL has already subcontracted $50,000 to UT (through ISSE) to continue this work. Another, similar, contract will be submitted in June.
- Investigate the impact of uncertainty in microgrid optimization: Undergraduate researcher (now masters student) Ethan Deakins has been investigating the impact of uncertainty on the current optimization models. He investigated two areas in particular. The first is how to model uncertainty in microgrids. While data collection has been delayed, access to ORNL's project will give Ethan the data necessary to perform thorough statistical analysis and to identify the distribution of errors in PV and load forecasts. Knowledge of this uncertainty can then be used to create more robust schedules. In preparation for the data Ethan has been developed a robust mathematical formulations for microgrid optimization.

Grad student Amelia at the neighborhood microgrid.

- Identify better ways to model components in a microgrid: Gas generators have been components in all of the microgrids we have considered. The physics of such generators, however, presented some modeling challenges. In particular, the on/off nature adds nonconvexities into the mathematical optimization model that (a) increase computation time and (b) makes it more difficult to compute real-time prices. Ph.D. student (graduated) Bernard Knueven identified improved formulations that mitigate these two concerns. We currently have a paper on this topic in the second round of revision for IEEE Transactions on Power Systems. We submitted a proposal to the NSF AMPS program through the ISSE center to continue this work. While the proposal was ultimately rejected, it was well received, obtaining an average score of "Very Good."

Evaluating sustainability and resilience in agricultural systems using an integrated, web-based app for on-farm self-assessment and resource discovery

(Team: Virginia Dale, Ecology and Evolutionary Biology/ORNL; and Don Hodges, UTIA Forestry, Wildlife and Fisheries)—*Final Report*

Products:

- Created a conceptual diagram and flow chart of App functionality
- Submitted to The University of Tennessee's Institute for a Secure and Sustainable Environment (ISSE) our summary report from stakeholder interactions in Yaqui Valley on June 5, 2017
- Prepared a manuscript summarizing the feasibility study of Apps for sustainable agricultural landscapes including a literature review, and recommended features. Upon its completion, we plan to submit the manuscript for publication in *Agronomy for Sustainable Development* in early 2018.

Findings: Based on interactions with agricultural researchers and stakeholders, as well as data and software experts, we have concluded that creation of a prototype application is beyond the scope of the current funded project. While the conceptual overview diagram has received enthusiastic responses, especially related to the real need for a tool that provides so much information from "one-stop-shopping," several experts have also commented on the technical software engineering challenges in making the database connections in real-time. Therefore, the task of prototype development and user-interface design would be part of future funded work.

In conclusion, the concept app would fill a gap in the current availability of decision support tools (DST) and provide useful information to farmers and other land managers. Key recommendations for the development of such a tool are:

- Geo-Smart: link GPS, GIS, remote-sensed and geographically referenced micro-sensed data
- Big Data processing within a hybrid multi-cloud server architecture
- Opensource software development platform such as OpenIoT (www.openiot.eu) to allow 'infinite' sensor integration, open data standards and continuous improvements to code and functionality
- Easy-to-use farmer-centered and icon-based mobile app linked to a deep web portal providing documentation of scientific basis for information and practical management recommendations
- Social networking through linked existing platforms as well as chat or short-message-service text to support peer-to-peer knowledge sharing

The ambitious scale of the concept DST would require multiple public and private institutional partners and a creative approach to long-term funding. Lessons learned from past DST efforts will be very useful for developing an integrated app for on-farm self-assessment and resource discovery.

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Socially Responsible Stormwater Management in the Face of Climate Change Uncertainty

(Team: Anahita Khojandi and Xueping Li, Industrial & Systems Engineering; Lisa Reyes Mason, Social Work; Kelsey Ellis, Geography; and Jon Hathaway, Civil & Environmental Engineering)—*Final Report*

Project Summary: This study is an interdisciplinary analysis of urban system resiliency to climate change that integrates methods from the social, hydrologic, and systems sciences. Specifically, this study focuses on urban flooding, a common occurrence that will be exacerbated by climate change, and the benefits of green infrastructure for flood abatement. Instead of traditional designs that aim to merely mitigate excess runoff or its associated economic costs, this study aims to incorporate the disproportionate effect of weather events and their associated hazards on communities with less social and economic advantages, highlighting the need to integrate these communities in flood abatement and resiliency planning.

Outcomes: We have produced a number of deliverables incorporating this work in 2016-2018, including peer-reviewed conference papers, presentations, proposal development, and media interviews.

Progress:

- IRB application to conduct phone surveys, neighborhood research meetings, and interviews submitted and partially approved.
- Focus group conducted with Edgewood Park Neighborhood Association.
- Interviews conducted with residents of Edgewood Park and Fairmont/Emoriland.
- Phone survey conducted by SWORPS/CARE, with Facebook online survey supplement. (Note: Analysis of survey data and paper publication will occur after the grant period. We will send ISSE citations and links to journal articles when available, for posting on ISSE's website.)
- Social vulnerability mapping of Knoxville census tracts completed.

Nutrient and microbial community implications associated with the addition of duckweed to wastewater remediation

(Team: Sarah Lebeis, Microbiology Department and Graduate School of Genome Science and Technology (GST); and Barry D. Bruce, Department of Biochemistry and Cellular and Molecular Biology and GST Program)

Project overview: Wastewater is the combination of liquid or water-carried wastes originating from sanitary outputs of human habitats, commercial or industrial facilities, and agricultural/livestock cultivations. Untreated wastewater generally contains high levels of organic material, high levels of potentially pathogenic microorganisms, excess nutrients, and toxic/radioactive compounds. As both global populations increase and land use for industrialization expands, there must be new, cost-effective, and energy-efficient means to ameliorate the environmental and health hazards associated with contaminated wastewater. The ultimate goal of wastewater management is environmental protection in a manner commensurate with public health and socioeconomic concerns. More importantly in many under-developed and even developing regions, both the technology and energy needed for traditional wastewater treatment does not exist. This proposal seeks to investigate the potential of an eco-friendly and low cost solutions using the aquatic plant duckweed to modulate the chemical and microbial components of municipal wastewater.

Research Update:

- Aim 1: Characterize dynamic changes to wastewater microbial community and metabolite composition following the addition of duckweed. Although the wastewater is available, we were not able to complete this Aim because we were waiting on our bioreactor to be converted for use with duckweed. Once the work on the bioreactor is completed, we will be able to run the experiment for a couple of weeks.

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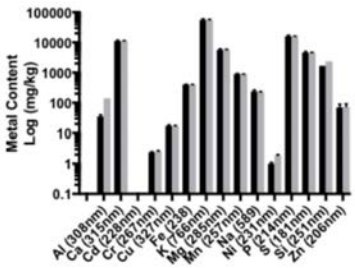

Dry weight content of many common plant associated metals. Two replicates of plants (grey and black) were washed and then lyophilized. Dry tissue was hydrolyzed in acid.

DNA extraction will take a couple of weeks, and then we will submit our samples to the Genomics Core for 16S sequencing and the Metabolomics Core for chemical analysis.

- Aim 2: Determine how duckweed Plant Growth Promoting Bacteria (PGPB) alter biomass production and wastewater remediation. We have made the most progress in identifying the bacterial isolates that we will use for this experiment. The Bruce lab has made tremendous progress in setting up a high-throughput screening assay for use to determine how bacterial isolates change the stability of photosynthetic pigments following high temperature or chemical treatment. The Lebeis Lab has made progress in performing comparative genomics on our bacterial isolates to select those that we predict will influence duckweed growth the most. We have chosen our 5 isolates (Sp7, Sp245, 37A, 38E, and RRCA) to add to our bioreactors based on: 1) their ability to protect duckweed from chemical and temperature stress, 2) their predicted diversity of secondary metabolites, and 3) their predicted number of metal transporter subunits. After we have completed the experiments in Aim 1, we will begin our experiments with Aim 2.
- Aim 3: Collaborate with BES Technologies (BEST) to test duckweed removal of ^{137}Cs from their radiochemical cleaning solutions. After all of the experiments for Aim 1 and Aim 2, we will transport our bioreactor out to BEST to perform the experiments for Aim 3. However, in the mean time we have begun to use ICP-OES to measure the metal content of the WT duckweed (Spirodela) and determined the content based on dry weight. This work was done in collaboration with Dr. Niki Labbe and involved Ms. Ola Noras, a BCMB rotation student.
  We tested their ability of Spirodela and bacteria to grown in Cd+, Co+, and Cu+ solutions. The thought is that these PGPB may provide either a "sink" for the benign remediation of these metals and possibly increase plant tolerance via the selective import of these metals. However, it is not known how the different PGPB take up these metals. To shed some light on this we have begun to none the genomes of the PGPB for metal uptake related genes. The number of potential transporters varies both by metal class and by bacterial species. This information can be used to guide the next set of experiments.

Funding Update: Submitted one proposal to the Plant-Biotic Interaction panel of the USDA-NSF, which is still pending. If we are not selected this year, we will resubmit this grant in the next call, which will likely be at the end of the summer again. Also submitted a DOE Early Career Research Program pre-application, which was not selected for a full application.

Hydraulic fracturing chemical effects on characterization of fractured shale particulates and their impact on hydraulic fracturing wastewater quality

(Team: Kim Carter and Angel Palomino, Civil and Environmental Engineering)

Introduction—The U.S. Energy Information Administration predicts a 30–40% increase in electricity generated by natural gas primarily produced through hydraulic fracturing (HF). HF requires the use of hydraulic fracturing fluids HFFs), composed of approximately 2 to 10 million gallons of fresh surface, ground or potable water mixed with chemicals (~50,000 gallons), including acid, proppants, friction reducers, iron stabilizers, gelling agents, and breakers for each well put into production. In Texas alone, roughly 120 billion gallons of water were used to fracture 40,000 wells from 2008 to 2014. This is more than the ~86.8 billion gallons of drinking water treated by KUB during that same time.

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During the gas production phase, approximately 20 to 70% of the HFF returns to the surface. The high volumes of contaminated water and limited treatment options have warranted environmental concerns due to the insufficient knowledge regarding chemical components and their impact on shale characteristics, water quality, and water reuse. The objective of this research is to investigate the impact of HFF additives on the physical/chemical properties of shale and the subsequent contribution to the wastewater quality.

Background—Chemicals such as oxidizers, acids and organic materials are used in HFF formulations to degrade the cellulosic gels and clean wellbores. The injected HFFs contacts the shale at high temperatures and pressures, which causes leaching of the shale formation constituents, changing both the physical/chemical characteristics of the shale and the composition of the HFFs. As the HFFs return to the surface as flowback fluid, produced water or wastewater, the water composition differs from the original HFFs. The degraded water quality renders it useless for consumption.

Figure 1 is a simplified schematic of the HF process. Potential reactions between the minerals in the shale and the oxidizers, acid, and organic additives may deteriorate the shale's integrity and hardness, and produce toxic and/or environmentally threatening contaminants. As shale particles deteriorate in the wastewater, generation of fine particles, colloidal particles, and suspended solids increases solution turbidity, which reduces water quality. Furthermore, increasing particle surface areas can promote microbial growth in aerobic and anoxic conditions causing diminished biocide efficacy, thus allowing for microbial communities to be brought back to the surface with the wastewater. Previous studies investigating the chemical effects of fluid-shale rock interactions used a synthetic fracturing fluid and brine and found that carbonate and gypsum precipitate from the shale. However, industry also uses corrosive organics, HCl, and persulfate, in their HFFs, which likely leads to dissolution of metal species into the HFF, yet their impacts are not taken into account by these studies.

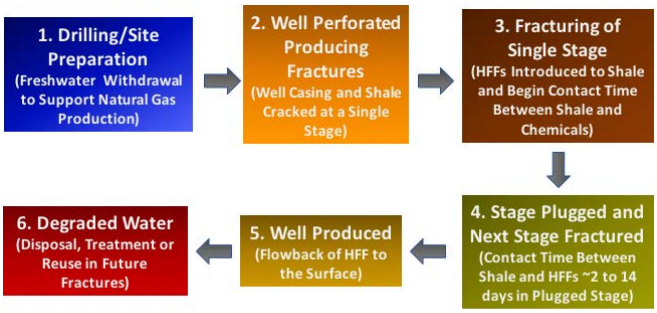

Fig 1. Simplified Hydraulic Fracturing Process

HFF impacts on the shale characteristics requires investigation of a synthetic HFF containing strong oxidizers, acids, and organic additives on the physical/chemical properties of shale. Specifically, this proposed work will explore how particle characteristics change with chemical additives solution contact time, and elevated temperatures. As changes in shale characteristics influence water quality, the information gained from this study will be used to develop a proposal that will investigate how the chemicals used in HFFs impact shale characteristics and how these reactions contribute to water quality reduction. Developing this treatment option would allow HFFs to be treated on-site, preventing wastewater spills during transportation, minimize HF waste, and protect water resources by reducing exposure risks.

Research Objectives—The goal of this proposed work is to determine the effects of using oxidizing agents, acids, and organic additives on the chemical and physical characteristics of shale at ambient pressures and elevated temperatures to establish a better understanding of the impact of HF processes on water quality. This requires:

- Determining the most critical HF chemical additives that alter the fractured shale's grain size distribution (GSD) and surface areas.
- Establishing a relationship between contact time with the critical HF chemicals identified and the impact on the shale's GSD and surface areas.

- Determining if leaching of metals from shale due to exposure to critical HFF chemicals.

Results—Experiments were run for the three objectives above and the results are shown in our project report.

Work to be Completed in Fall 2018—Hydraulic fracturing takes place at higher pressures that can impact the dissolution of metals in solution. This can have major implications for water quality from hydraulic fracturing uses, therefore, experiments will be performed in a high pressure device. These experiments are expected to be completed by December 2018.

Plans for Proposal and Paper Submissions—The results obtained so far clearly indicate that there remains a need for further studies to understand, quantify, and model the fundamental physical and chemical processes contributing to water quality degradation during the many stages of the fracking process. Therefore, the PIs plan to submit a proposal in November 2018 to NSFs Environmental Engineering Program.

The PIs plan to submit a manuscript to E*nvironmental Science and Technology* (a leading journal in environmental science and engineering) by October 2018.

Student Participation—One graduate student, Katherine Manz, was working on this project as a GRA. Katherine Manz is a recent graduate from the Bredesen Center and Dr. Carter's research group. She was working under the direct supervision and guidance of Drs. Carter and Palomino on this project and is currently editing the manuscript to be submitted this October.

Cyrus Jedari, current PhD student from Dr. Palomino's research group, will work on this project as a GRA this fall. He is working under the direct supervision and guidance of Dr. Palomino to provide analytical support on the PSA, SEM and XRD.

Leah Stephens is an undergraduate student that is working on this project under the direct supervision of Dr. Palomino and Dr. Carter. She has been and will continue to perform experiments and analytical work using the PSA and chemical analysis this fall. She participated in EUReCA, which is the undergraduate research symposium and exposition, in April 2018. She won honorary mention for her work on this project.

2017-18 Baker Center Energy and Environment Forum

(Team: Charles Sims, Economics Department and Baker Center; Paul Armsworth, Department of Ecology and Evolutionary Biology; Becky Jacobs, College of Law; Donald Hodges, UTIA Forestry, Wildlife and Fisheries)

On Feb. 15, 2018, Desiree Tullos, from Oregon State, gave a presentation titled: Dam Removal and Reoperation in an Age of Complex Hydro Systems. Desiree Tullos, PhD, PE, D.WRE is a Professor in the Biological and Ecological Engineering Department at Oregon State University. She earned her bachelor's and master's in Civil Engineering and her PhD in Biological Engineering. Her research team investigates the interactions between river engineering and the physical and biological processes of rivers. Projects focus on questions that range from the particle to basin scale, with the emphasis on the sustainable management of water resources. Example projects include: a) Physical and biological responses to river engineering, including dam removal and reintroducing large wood; b) analysis of reservoir operations under climate and land use change and associated impacts on flood risk reduction, water supply, hydropower generation, environmental flows, and sediment transport; c) Analysis of uncertainty in water resources, d) Turbulence and habitat of flow around vegetation and wood in rivers, and e) Sustainable flood risk management and infrastructure. In addition, she currently serve on the Independent Scientific Review Panel for Bonneville Power Administration's Northwest Power and Conservation Council and the board of directors for the Natural Heritage Institute. She has also served on two National Research Council committees, including one on Sustainable Water and Environmental Management in the California Bay-Delta. Her teaching emphasizes design-based learning in her primary classes: River Engineer-

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ing, Ecohydraulic Engineering, and Ecological Engineering–Systems Analysis.

During her visit she met with ISSE faculty including Jon Hathaway and Thanos Papanicolaou and graduate students from Civil and Environmental Engineering. She also toured TVA's River Operations Center in downtown Knoxville.

Microbial contamination, biofilm development and lead release in drinking water and in premise plumbing

(Team: Jayne Wu, Department of Electrical Engineering and Computer Science; Qiang He, Civil and Environmental Engineering; and Jiangang Chen, Public Health)

Summary of Progress: We have obtained proof-of-concept results for the detection of lead and bacteria using the proposed sensors. A journal paper and two conference presentations were produced on gram-negative bacteria detection by lipopolysaccharides (LPS)-specific aptasensors.

The research on lead detection is ongoing. So far we demonstrated highly sensitive and specific detection of lead in analytical background.

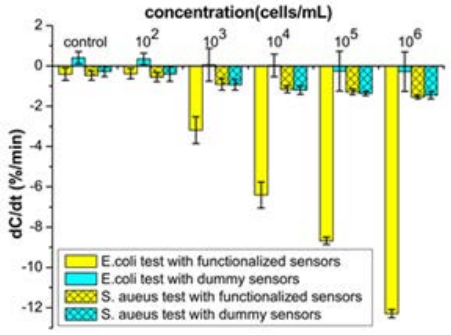
We have conducted preliminary sampling and testing of water samples from on-campus sites using established methods.

- Testing of first-draw samples detected elevated levels of metals such as iron; however, lead levels have been under the detection limit of ICP-AES, suggesting the need to develop more sensitive detection methods as proposed in this project.
- We have started the microbiological analysis of water samples with high-throughput sequencing to be used for the assessment of potential linkages between aquatic microbiomes and heavy metal leaching in the distribution systems.

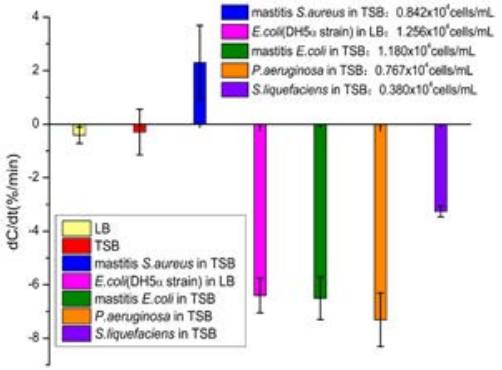
A proposal was submitted to NSF Cyber Physical Systems program in 2018 Summer. A second proposal is being planned as an unsolicited proposal to NSF Environmental Engineering program.

Future plans include the following:

- Select sampling sites with greater potential of lead leaching for subsequent monitoring and investigation.
- Submit one proposal to NSF within next 6 months.
- Publish at least a journal paper on lead detection.



Dose response of the LPS sensor to gram negative bacteria (E.coli) and gram positive bacteria (S.aureus). The limit of detection reaches ~100#/mL within 30 seconds



The sensor responses to different kinds of gram negative bacteria. Test results showed no appreciable difference in response for three E.coli strains (ATCC 25922, DH5α and a field isolate). Other types of Gram negative bacteria, Pseudomonas aerginosa (P. aerugi-nosa), Serratia liquefaciens (S. liquefaciens), were tested along with E. coli and S. aureus, also field isolates. The responses were within +/-30% of the standard curve of E. coli

Improving models of soil C stability by incorporating feedbacks between microbial C utilization, aggregate stability and agricultural management in response to simulated precipitation and drought

(Team: Sean Schaeffer, UTIA Biosystems Engineering and Soil Science; and Thanos Papanicolaou, Civil and Environmental Engineering)

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Overview: The frequency and intensity of extreme precipitation events, including both drought and heavy rainfall, are predicted to increase with climate change. Such events may affect the balance between biotic (crop, microbial) vs. abiotic (erosion, aggregation) drivers of microbial carbon use efficiency (CUE), and thus carbon (C) sequestration, in soils—as of now, however, the direction and magnitude of these effects is largely unknown. Conservation management practices such as cover crops and reduced tillage are effective strategies for sustaining soil organic carbon (SOC) content. However, with a changing climate, it is uncertain how these practices will affect the sequestration of carbon inputs into the soil. Thus, understanding the role of linked above ground and below ground processes, driven by the changing climate and management, is needed if we are to predict long term SOC stability and agroecosystem sustainability.

Our goal is to understand the coupled influences of intensive agricultural management on soil aggregate structure evolution, landscape water holding capacity, and microbial CUE, as well as soil strength and erodibility. The interactions and feedbacks of these processes influence the turnover rates of SOC with potential significant implications on residence times, and storage and transport of organic matter across the landscape.

With funds from ISSE, we have begun to collect preliminary data to provide a proof concept that feedbacks between microbial activity and soil moisture can affect the distribution of SOC on the landscape. Namely, we wish to set up experimental manipulations, where we can impose dry-wet cycles and observe changes in microbial CUE, soil aggregation and erodibility.

Work plan items:

- Recruit Graduate Research Assistant (GRA)—Graduate student (Aubrey Fine) was recruited by PI Schaeffer to work on this project. GRA Fine has worked with PI Papanicolaou to coordinate field sampling and design laboratory experiments.
- Collect field samples from two watersheds in Iowa and Tennessee that differ in soil management practices—GRA Fine collected soil samples from the Iowa River Watershed at the Intensively Managed Landscapes Critical Zone Observatory (IML-CZO). The IML-CZO site is part of an NSF funded research site (Papanicolaou is a PI) with agricultural soils that vary in management (crop residue retention and tillage) and in hydro-biogeochemical characteristics (soil texture and organic matter content). GRA Fine analyzed soils for microbial CUE, biomass and organic C fraction content.
- Experimental manipulations of dry-wet cycles, microbial CUE, and soil aggregation

Changes to work plan: (1) It was decided to focus on small scale laboratory manipulations of soil moisture rather than the proposed rainfall simulator studies. It was felt that the smaller scale was more tractable and controllable. This decision

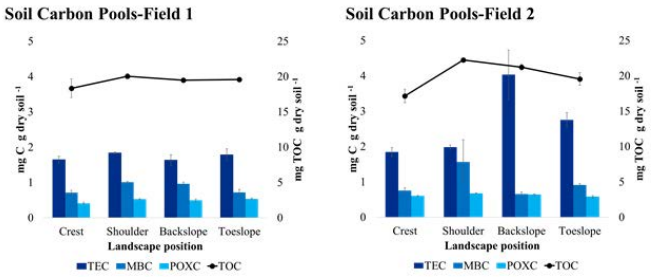

Figure 1. Mean size of soil pools measured at four landscape positions in Fields 1 and 2. TOC is total organic C (right axis), TEC is total extractable C, MBC is microbial biomass C, and POXC is permanganate oxidizable C. Error bars show standard error.

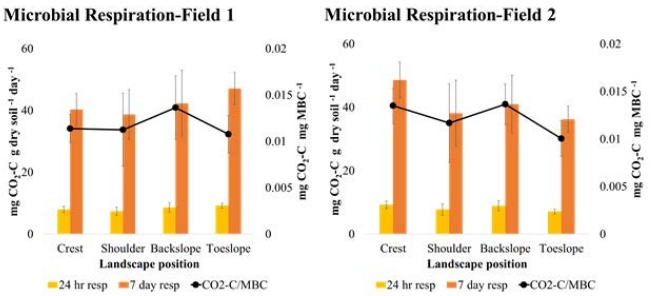

Figure 2. Mean soil respiration rates for four landscape positions sampled in Fields 1 and 2. Data are expressed in mg CO2-C per g dry soil per day (t=1 and 7 days) and mg CO2-C per unit microbial biomass C (MBC) (right axis). Errors bars show standard error (n=6).

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was made in consultation with ISSE in December, 2017. (2) Rather than the Obion and Iowa River watersheds, the laboratory incubations study is being conducted with soils collected from the East Tennessee Research and Education Center (ETREC). The soils from this site are more easily accessible, and similar to those in West Tennessee. Also, soil type is not important for the mechanistic processes being studied in this experiment.

Two agricultural fields with contrasting land management were evaluated for soil C pools and microbial activity at four landscape positions along a slope (moving downslope: Crest, Shoulder, Backslope, Toeslope). In Field 1, where the previous year's crop residues were retained on the soil surface, C pools among landscape positions were similar; Field 2, which is wetter and where residues were not retained, had relatively larger C pools and higher concentrations of bioavailable C that varied with landscape position. Microbial respiration, an indicator of microbial activity, showed contrasting trends between the two fields; microbial activity was greatest at the Crest for Field 1 and the Toeslope for Field 2. When normalized to the size of the microbial biomass C pool, both sites had maximal activity at the intermediate Backslope position. Differences in soil wetness and land management between Fields 1 and 2 (i.e., residue retention) likely impacted C and N availability to soil microorganisms. To adapt to these differences in moisture and substrate availability across the landscape, soil microbes could have altered their CUE; this idea is supported by our gross calculation of CUE (data not shown), so will be further investigated during the laboratory incubation experiments.

Instrumenting an outdoor laboratory at the UT Gardens constructed wetlands

(Team: Andrea Ludwig, UTIA Biosystems Engineering and Soil Science; Sue Hamilton, UTIA Plant Sciences; Chris Graves, UTIA Forestry, Wildlife & Fisheries)

Summary of Progress—Significant progress has been made toward creating and utilizing the created wetlands at the UT Gardens as an outdoor

Visitors use the new elevated boardwalk to experience wetland wildlife from a new perspective.

experiential learning laboratory. In February 2018, principal investigators met with representatives from the instrumentation vendors on site to discuss project needs, plan installation, and create a list for project bid. A non-compete justification application was made and granted to the principal investigator, which created a path for procurement without the need for a bid process. The full suite of instrumentation has been ordered and invoiced, and the team is awaiting its arrival. Installation of all field instrumentation is scheduled to begin the last week of October 2018, and it is expected to take approximately 2-3 weeks. In May 2018, an elevated boardwalk was constructed that allows visitors to experience the wetlands from an entirely new perspective.

Field sampling supplies needed to conduct the annual ecological inventory were procured in June 2018. This included waterproof wading boots and waders, kick and drift nets, tweezers, sample trays, and clear-bottomed buckets. These supplies will be used in all subsequent annual ecological inventories conducted by students in the Forestry Wildlife and Fisheries department.

Several education milestones have been completed at the site related to this effort. Interpretive signs were designed, and the hardware and building supplies have been procured. Signs are scheduled to be up by late October 2018. Also, a wetland scavenger hunt activity was developed for Garden Campers.

Presentations—The created wetlands are a demonstration site for visitors and a place where

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Two examples of interpretive signs that will be printed and displayed this fall 2018.

watershed professionals can show their clientele what these types of systems can look like in a residential garden landscape. In August 2017, Extension Specialists along with local municipal government partners met with a local landowner at the project site to engage with them about what kind of created wetland would satisfy their needs on their property. The homeowners were able to see a variety of different planting strategies, create a dialogue with the project designer, and settle on reasonable expectations for a created wetland at their property.

Other presentations of work related to the outdoor laboratory at the created wetlands during the reporting period included:

- Oct 18, 2018 – "The Tennessee River Runoff 5K Experience" presented at the annual conference of the Tennessee Stormwater Association, Fall Creek Falls Inn, Pikeville, Tennessee. The created wetland was a central piece of the community water quality festival that accompanied the 5K race.
- June 30, 2018 – Created Wetlands at the UT Gardens Junior Garden Camp program. Here, a scavenger hunt activity was used to introduce wetland vocabulary and create a structured experiential learning activity for 30 students ranging from first to sixth grades.

Students Involvement—The UT Wildlife & Fisheries Society conducted the second annual ecological inventory of the insects, amphibians, and dominant plant species at the created wetlands. This involved five undergraduate students from the student club to collect samples and make field observations, and one of those students taking the lead on compiling field data and presenting a report of findings. Of note, in each of the four wetland ponds, mosquito predators (dragonflies, damselflies, and water beetles) were documented.

"Garden Campers" explore the created wetland area just before competing in pairs in a wetland scavenger hunt, where they learn new vocabulary terms and find life throughout the wetland.

A recent graduate (May 2018) from the Environmental and Soil Science program was granted an Extension Internship for the summer of 2018. During this experience, the intern helped to deliver the Junior Garden Camp program at the created wetlands. This experience in part lead to their application for a position with University of Tennessee Extension as a Horticulture-Youth Education County Agent. The review of applicants is currently still underway.

Future Plans—The water quality monitoring instrumentation will be installed in Oct-Nov 2018. Once this is in place, a website will be created by the product vendor that will publish realtime

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water quality parameters of dissolved oxygen, turbidity, temperature, and pH. From this data archive, a classroom module targeting high school students will be created and published online by mid-spring 2019. The module will be tested with Tennessee 4H educators in December 2019 during an annual inservice training program. Feedback from these end users will be incorporated into the module before final publishing and dissemination for classroom use.

Water quality data will be partnered with climate data from a proximate university-controlled weather station. A preliminary data set will be created to evaluate the impacts of weather events (hydrologic perturbations from runoff events) on dissolved oxygen trends in the wetland ponds. Site variables (such as abundance of floating aquatic vegetation, season, presence of liner, and dominant vegetation type) will be considered when investigating differences in trends between ponds.

New 2017-18 Seed Grant Projects

(These new seed grant projects were awarded in June 2018 for one-year starting July 1:

Investigate Gas Production from Organic Matter in Sediments to Estimate Methane Release from Water Holding Structures

(Team: Abhijeet P. Borole, Chemical and Biomolecular Engineering; and Thanos Papanicolaou, Civil and Environmental Engineering)

Proposed Research Area: Methane vs. Bioenergy Production from Sediments in Water Bodies.

Problem Statement: Human beings have interrupted water flow in nature for ages to extract water for irrigation or energy from hydroelectric dams. These water bodies accumulate natural organic matter that degrades in the water column producing carbon dioxide. Anaerobic sediments produce methane, a potent greenhouse gas. Large amounts of organic matter accumulate behind dams as well as in calm river waters, on the order of 200-530 x 106 tons C/year, releasing significant amounts of CO2 & CH4. Removal of the sediment is necessary for long term operation of the water systems. We propose to investigate methane release from dam sediments and natural plant biopolymers to improve estimation of this contribution to the carbon cycle. Additionally, we propose to get preliminary data on valorization of the sediment organics via H2 production. This approach can lead to reduced GHG emissions, improved economics of sediment removal, production of clean H2 for transportation and as an energy source, and minimize anthropogenic effects on the global climate change.

Gas Driven Fracture During Gas Production using 3D Synchrotron Computed Tomography (SMT)

(Team: Khalid Alshibli, Civil and Environmental Engineering; and Claudia J. Rawn, Materials Science and Engineering)

Description of proposed research area: Methane gas hydrates, crystalline inclusion compounds formed from methane (CH4) and water, are found in marine continental margin and permafrost sediments worldwide because they can be formed at quite low temperature and high pressure conditions that is known as hydrate-bearing sediments. The availability of methane hydrates and the expected increase in energy demand encouraged researchers to consider methane production from methane hydrates as a potential energy source. It is estimated that more than 95% of methane hydrates occur in marine environments where the conditions of high pressure and low temperature are satisfied. The production of methane from hydrate-bearing sediments requires hydrate dissociation for releasing mobile methane gas in sediments prior to gas production operation.

The injection of carbon dioxide (CO2) into hydrate-bearing sediments can liberate methane (CH4) and sequester CO2 in hydrate form. This phenomenon, known as CH4-CO2 exchange or CH4-CO2 replacement, creates a unique opportunity to recover an energy resource, methane CH4, while entrapping a greenhouse gas, carbon dioxide CO2. Despite extensive research on hydrate dissociation and in-situ hydrate production, there is a big knowledge gap that needs to be resolved

to develop technical and economically viable methane production strategies from gas hydrate reservoirs. A comprehensive understanding of underlying physical processes of both the emergent phenomena (e.g., fines migration, clogging, over-pressurization, and gas driven fracture generation during gas production) and CH4-CO2 replacement in hydrate-bearing sediments is required. Such understanding can be used to evaluate, design, and monitor/control gas production strategies.

Multiphase flow is defined as simultaneous flow of two or more fluids with different states (i.e., gas or liquid). Fines migration and clogging in single-phase and multi-phase flow have been investigated using two-dimensional (2D) microfluidic pore models, three-dimensional (3D) porous sediments models, and numerical simulations. During methane production, fines may migrate and/or clog through the pore space of sandy sediments depending on fines concentration, flow rate and geometry and topology of the pore scale (i.e., pore size distribution, throat size distribution and the ratio of the size of the pore throat to the size of the fine particle). It is known that the preferential path of gas invasion for clay-rich sediments usually takes place through conduit opening or fracturing. However, Jung et al. (2012) showed that during multiphase flow of CO2 through saturated sandy sediments with small amount of fines fraction (i.e., ~4%), fracture could also develop due to fines clogging. Therefore, to better explore the mechanisms of gas production from hydrate bearing sediments, a comprehensive understanding of the associated physical processes such as fines migration, clogging and gas-driven fracture is needed.

The objective of this study is to identify the evolution of gas flow paths and patterns that are associated with underlying coupled processes of fines migration, clogging, over-pressurization, and gas driven fracture, through unique in situ experiments that involve monitoring gas invasion of porous media with fines. 3D direct visualizations of fines clogging, and gas driven fracture are will be monitored by means of 3D Synchrotron Micro-computed Tomography (SMT) imaging. Successful completion of the project will provide fundamental understanding of underlying coupled processes of fines migration, clogging, over-pressurization, gas-driven fracturing to evaluate optimal conditions for the various production strategies (most notably, depressurization and CH4-CO2 exchange). This in turn allows us to select the most efficient production technology adequate for the local geological/geographic conditions (e.g., water depth or permafrost depth, pressure-temperature condition, sediment type, reservoir thickness, hydrate concentration).

Awards

Faculty/Staff Awards

- **Thanos Papanicolaou** (TNWRRC Director) was awarded the 2018 Hans Albert Einstein award winner from the American Society of Civil Engineers (ASCE). It is perhaps the most prestigious distinction that someone in hydraulic engineering can earn.
- Former TNWRRC Director, **Bruce Tschantz**, is honored for his lifetime achievements in dam safety with a Public Dam Safety award.
- ISSE researcher **Joshua Fu** has been chosen as the recipient of the prestigious 2018 Lyman A. Ripperton Environmental Educator Award for his education efforts related to controlling air pollution.

Student Awards

- **Leah Stephens** participated in EUReCA, which is the undergraduate research symposium and exposition, in April 2018. She won honorary mention for her work on an ISSE seed grant project.

Goals/Future Plans

Goals/Future Plans

The Institute for a Secure and Sustainable Environment (ISSE) will develop a strategic plan to grow the research, educational, and outreach activities at the University of Tennessee, including both the University of Tennessee at Knoxville (UTK) and UT Institute of Agriculture (UTIA), to promote the development of policies, technologies, and educational programs in response to pressing environmental and security issues facing the state, the nation, and the globe. The new ISSE director will work with the ISSE Advisory Committee to develop ISSE's strategic objectives, focus areas, and a five-year plan. ISSE plans to continue funding seed grant proposals and to support key affiliated faculty members annually. The funding will be concentrated around the themes of natural and built systems sustainability with a focus on the food, energy, and water nexus.

ISSE will continue supporting the new initiative with UTIA to grow a Research Coordination Network (RCN), designed to identify transdisciplinary research opportunities for scientists in the US, China, and other countries focusing on the nexus of food, energy, and water systems (FEWS). This initiative, termed "Food-Energy-Water Systems Transdisciplinary Environmental Research Network" (FEWSTERN), partners with three NSF-China awards to three teams of Chinese institutions, led by Nanjing University, South China University of Science and Technology, and Remin University of China, respectively, to develop research priorities transcending US and Chinese grand challenges. A pending NSF proposal is targeted to grow the network and expand it to more institutes in the two nations and others.

Plans for the centers housed by ISSE from July 2018 to June 2019 are below.

The primary goal of the **Tennessee Water Resources Research Center (TNWRRC)** is to assist the state of Tennessee and its entities in developing and implementing programs for sustaining high quality water, serving as a link between the academic community, federal and state government water-related organizations, the private sector, and local communities. The following are planned activities to help meet that goal:

- Build a new leadership team and develop a strategic plan for the TNWRRC;
- Build a team of key water-related faculty members and researchers at both UTK and UTIA;
- Renew the EPA Centers of Excellence in Watershed Management through a collaboration with EPA Region 4, TDEC, and UTIA and conduct more research and educational activities through the platform;
- Continue to offer two statewide training and certification programs for the Tennessee Department of Environment and Conservation (TDEC) and develop new courses as the need arises;
- Focus on new initiatives, such as bank erosion, that relate to statewide issues of water quality and infrastructure;
- Focus on research themes pertinent to human decision making and water;
- Conduct workshops/webinars on a semi-annual basis to highlight best management practices for important water topics;
- Continue to work with the TNWRRC Advisory Board to fund USGS 104(b) research grants that meet the needs of state agencies.

The **East Tennessee Clean Fuels (ETCF) Coalition's** future plans include:

- Maintaining a comprehensive Constituent Relationship Management (CRM) database to improve coalition operations and efficiency;
- Working to increase the overall total gasoline-gallon equivalents (GGEs) and reduce greenhouse gas (GHG) emissions across Tennessee over calendar year 2017 amounts;
- Hiring one or two UT students for internship opportunities during the academic year;
- Co-hosting the 4th Annual Tennessee Sustainable Transportation Forum with TDEC and Tennessee Department of Transportation (TDOT), highlighting new research and

Goals/Future Plans

technologies that improve transportation efficiency, reduce vehicle emissions, and address the mobility needs of all Tennesseans, honoring winners of the TDEC/TDOT 2018 Tennessee Sustainable Transportation Awards, demonstrating alternative fuel vehicles, and recognizing a new class of certified Tennessee Green Fleets; and

- Supporting the State of Tennessee's distribution of its allocation of Volkswagen Environmental Mitigation Trust settlement fund, particularly advocating for funds to be allotted to AFV purchases and infrastructure for private and public fleets across the state.

The primary goal of the **Tennessee Methane Center** is to research sustainable methods to utilize methane for energy, water, and agriculture in Tennessee, as Tennessee and the United States become a methane-based economy. The main activities include:

- Funding students and one Post-Doc in this area to make sure Tennessee has the resources to be a major research and application center for methane;
- Applying for major funding from NSF, DOE, or other federal agencies to further establish multi-disciplinary and multi-institutional research and training in methane-related technologies; and
- Inviting national and international methane experts to UTK to provide lectures and interactions with faculty and students.

2017-2018 Publications & Presentations

ISSE Related Publications

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